The effects of yoga on sports performance and health

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Tilak Raj

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Stretching is frequently used in an attempt to increase flexibility and enhance athletic performance. Stretching and similar techniques have also been used in sedentary and clinical populations to increase the mobility of joints, reduce pain and improve cardiovascular health. Yoga is not only a stretching exercise, but uses a holistic approach that improves flexibility and incorporates mental awareness. However, yoga has seldom been investigated in elite athletes or a representative cross-section of society.

In the first three studies of this research, a yoga intervention was employed to assess the influence of yoga on flexibility, balance, and sport performance (i.e. sprinting ability) in rugby players. Furthermore, in a fourth, large, cross-sectional study, I examined the effects of practising yoga on cardiovascular health markers (total cholesterol, blood glucose, heart-rate variability (HRV), and arterial stiffness) in healthy adults.

Findings in the first study suggest that two, 1 hr yoga sessions per week for 12 weeks resulted in a significantly reduced postural sway signal in the 2-legged eyes closed antero-posterior (-109.7% ± 82.9) and medial-lateral (-115.5% ± 92.1, mean ± 95% CI, $p<0.005$) directions in a yoga group (n = 15) compared to a control group (n = 14), indicating an improved balance ability in rugby players. In the second study, incorporating 8 weeks of yoga, including two, 1 hr sessions per week I found a minor, non-significant improvement in split times in the yoga group (-3.2% ± 10.4, -0.7% ± 9.0 for the 5 and 10 m sprints respectively, mean ± 95% confidence interval) compared to controls (-0.4% ± 10.2, 0.4%

± 7.9). Additionally, no significant change was found in the flexibility of the yoga group but the control group significantly decreased flexibility over this period. Based on the results of the first two studies (two, 1 hr yoga sessions either over 8 or 12 weeks resulting in minor changes to balance and performance in the male rugby players), a decision was made to investigate a more concise intervention that included shorter yoga sessions (better fit into busy schedules of players), included advanced postures, and had quick progressions through postures to determine if a more practical intervention could be equally effective for players.

In the third study, a new yoga intervention which included advanced postures with a shorter session time (2 sessions/week for 30 min each, rather than 1 hr each) over a similar time frame (12 weeks) was carried out to observe the effects of yoga on flexibility measured at the hip and knee and sprint performance (over 5, 10, 15 and 20 m) in female rugby players. The five players in the yoga intervention group demonstrated significantly improved straight leg raises 29.1 ± 15.3 degrees (mean % change ± 95% CI, $p < 0.05$) compared to the control group 2.9 ± 18.6 (mean % change ± 95% CI, $p > 0.05$). Players in the yoga group also significantly improved their 5 m sprint time -10.4 ± 10.2 (mean % change ± 95% CI, $p < 0.05$) compared to the control group 9.9 ± 6.1 (mean % change ± 95% CI, $p > 0.05$), suggesting that yoga may help female rugby players improve or at least maintain their sprint performance and flexibility during the season.

Yoga has also been associated with health improvements, particularly for the cardiovascular system. In the fourth study, the associations between yoga and clinical measures of cardiovascular health was investigated in a large cross-sectional study. New Zealand adult participants were split into those that regularly practised yoga and those that did not. Overall, the regularly-practicing yoga participants had significantly lower carotid-femoral pulse wave velocity (-0.13 ± 0.28, $m.s^{-1}$, $p < 0.05$, mean ± 95% CI) and systolic blood pressure (-2.0 ± 2.6, mmHg, $p < 0.05$), higher flexibility (12.7 ± 1.9 cm, $p < 0.01$), and higher total physical activity levels (1035.1 ± 671.3 $METmin.week^{-1}$, $p < 0.01$) compared to the control group not practicing yoga. The control group was significantly taller (2.7 ± 1.7 cm, mean ± 95% CI, $p < 0.002$), heavier (8.2 ± 4.1 kg, $p < 0.01$), had more muscle mass (2.9 ± 1.5

kg, $p < 0.05$), higher body mass index (2.0 ± 0.7, $p < 0.05$), higher waist-hip-ratio (0.05 ± 0.02 cm, $p < 0.01$), and higher body fat (2.9 ± 3.1 kg) than the yoga group. Furthermore, the control group had higher blood glucose levels (92.0 ± 15.2 mg/dl) compared to the yoga group (90.6 ± 13.8 mg/dL, $p = 0.36$), but the yoga group had higher total cholesterol compared to the control group (192.1 ± 40.5 and 176.7 ± 42.8 mg/dL mean ± SD, for yoga group and control group respectively, $p < 0.01$). When the groups were separated into age categories the carotid-femoral pulse wave velocity was found to be significantly lower in younger (18 to 39 years) and older (60 years and above) yoga participants compared to controls. The findings suggest that regular practice of yoga is associated with reduced carotid-femoral pulse wave velocity and improved clinical measures of cardiovascular health.

Overall, yoga appears to improve the flexibility of those who regularly practice it (i.e. 1 x per week) over a long time period (i.e. 3-months). In particular, yoga was found to be associated with improved eyes closed balance in rugby players and either maintained or improved 5 m sprint performance and improved some cardiovascular health indices among healthy adults. Overall, improved flexibility may be useful for daily physical functioning and for maintaining lifelong physical activity among the general population and for sport performance of athletes.

Keywords: rugby, exercise, proprioception, sports performance, balance training, range of motion, acceleration, stretching, cardiovascular risk, arterial stiffness

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Table of Contents

List of Tables

List of Figures

Chapter 1

Introduction

Today, sport is a career for the few talented individuals who participate at the highest level. Some of the most popular elite team sports are football, hockey and rugby. Rugby is unique because it requires both collision and evasion training by the same players. Rugby involves frequent, sudden, directional changes and shifts in momentum (Fong, Hong, Chan, Yung, & Chan, 2007; Schiftan, Ross, & Hahne, 2014). Since rugby requires quick changes in direction and velocity along with high impact collisions, players are at a higher risk of musculoskeletal injury occurring during practice or in match situations (Green, Trewarnta, & Stokes, 2009; Kara, 2012) which may eventually affect the players performance. To improve or maintain performance and decrease the incidence of injury, rugby players should possess a combination of fitness components including strength, stamina, speed, acceleration, flexibility, dynamic balance and static balance (Brooks., Fuller., Kemp., & Reddin., 2005; Kara, 2012; Sabesan, Steffes, Lombardo, Petersen-Fitts, & Jildeh, 2016). Researchers have recommended incorporating a multi-disciplinary approach to training in sports like rugby, including Tai Chi, Pilates, and yoga (Ni et al., 2014; Penman, 2012; Pritha, 2009). Yoga includes various physical postures, each focusing on a specific body part (Brunelle, Blais-Coutu, Gouadec, Bédard, & Fait, 2015).

Although it is well understood that regularly completing exercises popular in western cultures such as running or swimming improves the health and fitness of individuals (Boreham et al., 2004; Goenka & Lee, 2017; Hotta et al., 2013; Kruse & Scheuermann, 2017; Laurent et al., 2006; Lear et al., 2017; Mcdaniel, Ives, & Richardson, 2012; Myers et al., 2015; Nishiwaki, Yonemura, Kurobe, & Matsumoto, 2015; Scheuer & Tipton, 1977), the use of traditional eastern movement practices, like yoga, is not well-researched in medicine. Yoga is an ancient Indian discipline that has been practised for centuries. Yoga incorporates static and dynamic poses (asana) and is now practised worldwide. Yoga also involves relaxation and breathing techniques (pranayama) which have been found to improve well-being and health (Doria, De Vuono, Sanlorenzo, Irtelli, & Mencacci, 2015). Although yoga has proven to be useful in improving some sport-specific movements including balance and skating performance (Pauline & Rintaugu, 2011; Tran, Holly, Lashbrook, & Amsterdam, 2001), its effect on performance such as sprinting, particularly in rugby players, has yet to be investigated.

Researchers postulate that incorporating the physical attributes of yoga into athletes' training may also be useful for improving balance, performance, reaction time, and possibly reducing the time required for recovery. Thus, it was anticipated that improving balance and flexibility using a sport-specific yoga intervention may improve rugby players' sport performance. Therefore, as part of this research, yoga's effects on the balance and sprint performance of well-trained male and female rugby players were assessed.

In recent years, yoga has been found effective at increasing muscular strength by 31%, endurance by 10%, and VO2 max by 7% (Shiraishi & Bezerra, 2016; Tran et al., 2001) and increased flexibility from 26.4 ± 10.4 cm to 41.4 ± 4.4 cm after 4 weeks (Gawinski, 2012). Yoga interventions have also been shown to be effective in decreasing systolic (-5.8 ±12.5 mmHg) and diastolic (-4.12 ± 6.55 mmHg) blood pressure (Cramer et al., 2014), while also decreasing depression 9 ± 3.5% to 7.5 ± 3.3%, anxiety 7.6 ± 4.5% to 6 ± 4.2%, and stress 11.2 ± 3.3% to 10.1 ± 3.2% (Doria et al., 2015; Tayyebi, Babahaji, Sadeghi, Ebadi, & Eynollahi, 2011). Despite the positive results, there is a dearth of evidence on the effects of regular yoga on clinical outcomes such as arterial stiffness and blood pressure (Cramer et al., 2014; Miles et al., 2013). Therefore, another aim of this thesis was to investigate the effects of yoga on cardio-metabolic health in a group of volunteers who regularly practice yoga and those that do not practice yoga in New Zealand.

1.1 Thesis statement and aims

The overarching aim of this thesis was to determine the effects of yoga on rugby players' sprint performance and whether regular yoga practice affects cardiovascular risk factors in a healthy, adult population. To achieve this, the following specific aims have been identified:

i. Study 1: To determine the effects of a 12-week yoga intervention implemented in the natural environment on the balance of male rugby union players.

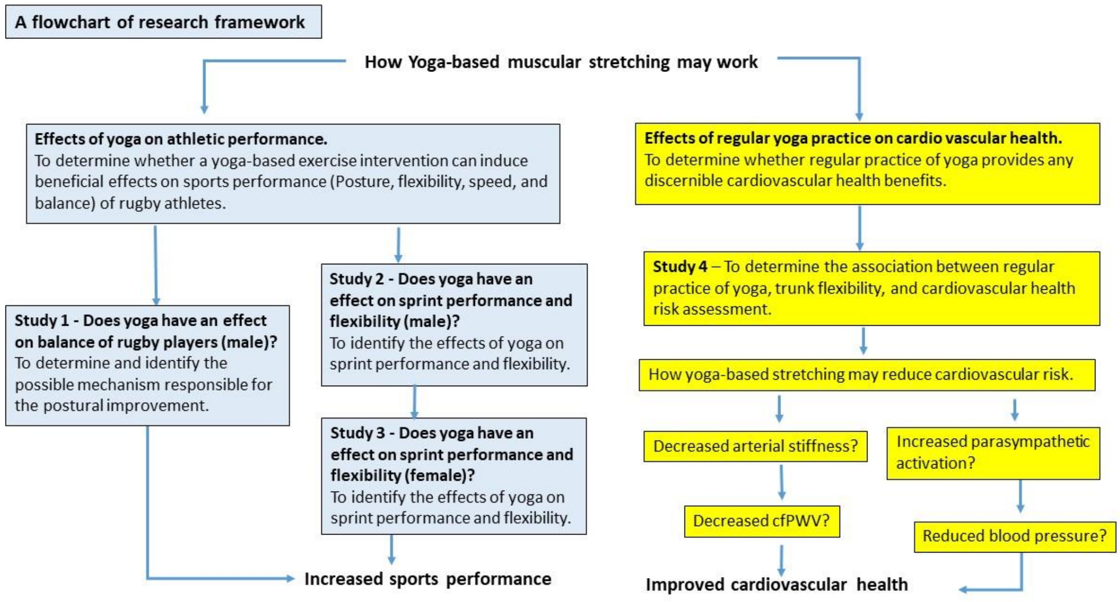
ii. Study 2: To determine the effects of a 12-week yoga intervention on flexibility and sprinting of male rugby union players.

iii. Study 3: To explore the effects of an 8-week yoga intervention on flexibility and sprinting of female rugby union players.

iv. Study 4: To determine the association between regular, long-term yoga practice on trunk and hamstring flexibility and indices of cardiovascular disease in a healthy adult population.

The progression of the research is indicated in a flow chart (see Figure 1).

Figure 1. Flow diagram of thesis progression.



1.2 Thesis format

To test the above hypotheses, I conducted four studies to investigate each of the research aims individually. Therefore, the nature of this research lends itself to a 'thesis by papers' approach, whereby each chapter of the thesis is written in the format of an academic research journal article. Each paper in the thesis contains an introduction and background section related to the research covered in that chapter as well as a discussion of the results. Additionally, a description of the findings from each study and how they relate to the following study has been included between chapters. All references are listed collectively in the reference section at the end of the thesis. Chapters that have been published in peer-reviewed journals are situated in the appendix at the end of the thesis.

1.3 An overview of the following thesis chapters

1.3.1 Background

To develop an understanding of the research area, investigations on the background of yoga, rugby, and cardiovascular disease were conducted. There were two foci of this thesis, the first was the application of yoga for the improvement of rugby players' game-related performance measures. The second was to investigate the influence of yoga on cardiovascular health parameters in healthy adults.

The availability of research on the effects of yoga on athletic performance is scant, particularly when yoga is delivered as an intervention in-season. There is also debate as to what mechanisms might be responsible for changes in sports performance. Meanwhile, it is not fully understood how yoga is associated with cardiovascular health, specifically pulse wave velocity therefore, several key areas were considered to be addressed in this research:

I. The use of yoga in a collision team sport (rugby) environment and the effects of a yoga intervention on players' balance.

II. The effects of yoga on male rugby players' flexibility and sprinting performance.

III. The effects of a yoga intervention on the flexibility and sprinting ability in female rugby players (as compared to males in previous studies).

IV. The association between regular practice of yoga and cardiovascular health in adults.

To address these gaps in the literature, four different studies were undertaken.

1.3.2 Study 1: Effects of a 12 week yoga intervention on postural sway in male rugby union players

In line with the aim and purpose of the thesis outlined in Figure 1, this research sought to determine whether yoga had an effect on postural sway in rugby players if delivered alongside normal rugby training during the season. Postural sway is an indicator of balance, one's ability to come back to a steady position after any postural perturbation. This study analysed the impact of a yoga intervention on postural sway.

1.3.3 Study 2: Association between hamstring flexibility and sprint speed after 8-weeks of yoga in male rugby union players

This study aimed to identify whether yoga had the ability to improve the sprint performance of rugby players by altering their flexibility if practised alongside their regular rugby training. To achieve this, the length of the intervention was 8 weeks and each yoga session was 60 min long, 2 times a week (similar to study 1). The aim of this study was to determine differences between the yoga group compared to the control group who completed their normal rugby and fitness training without yoga.

1.3.4 Study 3: Association between hamstring flexibility and 20 m sprint speed after 12 weeks of yoga in female rugby union players

This study aimed to explore if the findings in study two could be achieved in a shorter yoga intervention, among female rugby union players. Therefore, a yoga intervention shorter in duration (30 min, compared to 60 min in study two), practised two times a week, over a longer period (12 weeks, compared to 8 weeks in study two) was delivered. This study was performed on female rugby players as this is becoming a popular sport among women and little information exists on the use of yoga in female rugby players. Simultaneously, independent measures of flexibility were included to investigate flexibility and sprint speed improvement. To give a more specific and accurate measure of flexibility, a combination of popliteal angle and straight leg raise tests (Czaprowski et al., 2013) were used in this study rather than the sit and reach test. I also used a four split (5, 10, 15, and 20 m) sprint assessment to assess the sprinting ability (compared to the three-splits of study 2).

1.3.5 Phase 2: Study 4: Effects of yoga on cardiovascular risk factors and health parameters in a healthy adult population

Based on the information available in the literature, it is understood that athletes who are young and physically active will reduce their chance of developing heart disease. Therefore, this study aimed to investigate whether regular yoga (a specific form of physical activity) was beneficial at reducing risk factors for cardiovascular disease. To achieve this, a cross-sectional study was used, which allowed examination of the associations between people regularly practising yoga compared to healthy non-yoga practising adults. This study used clinical measures of cardiovascular health including carotid-femoral pulse wave velocity, blood pressure, resting heart rate, heart rate variability, lipid profile, glucose metabolism, and augmentation index with other anthropometrical (height, body weight, body fat, body mass index, waist to hip ratio), physical (flexibility, weekly physical activity) and psychological factors (perceived stress).

Chapter 2

Background

2.1 Yoga

Yoga is defined as an ancient Indian exercise (Ernst, Pittler, Wider, & Boddy, 2008) characterized by its various forms and multiple practice components (Schmid, Van Puymbroeck, & Koceja, 2010) such as breathing control and meditation. Yoga is separated into six categories: Jnana yoga, Karma yoga, Bhakti yoga, Mantra yoga, Raja yoga, and Hatha yoga (Doria et al., 2015).

Jnana yoga is referred to as yoga of knowledge and mainly focuses on the union of the mind and body through philosophical practice (Yogeshwar, 1994). Whereas karma yoga is referred to as an unattached practice that requires one to do work without any motive behind it. Bhakti yoga is the yoga of devotion and requires the person to practice various rituals. Raja yoga is a psychological method of yoga leading people to develop improved mental concentration. Mantra yoga practice involves reciting and repeating utterances for a particular duration and time. Finally, Hatha yoga mainly focuses on Asana (yoga postures), and Pranayama (breathing techniques), along with Dhyana (meditation).

More specifically, Asana is commonly referred to as yoga postures, is where the participant holds a physical position for an extended period of time. Pranayama is where the participant uses various breathing techniques to either maintain, increase or decrease the speed of inhalation and exhalation. Dhyana is when individuals learn how to focus the mind on a particular object, thought, or activity.

Since yoga has a variety of practice intensities (slow-paced to high-intensity), the practice also varies from school to school and according to an instructor's teaching style. Yoga schools such as 'Sivananda yoga', and 'Iyengar yoga' practice traditional forms of yoga. However, the most commonly practised form of yoga around the world, particularly in western countries is the Asana part of Hatha yoga (used in this study, hereafter addressed as yoga). This encourages the participant to focus on the body to increase awareness while stretching major muscle groups to gain flexibility and improve physical strength (Pauline & Rintaugu, 2011; Schmid et al., 2010; Tran et al., 2001).

Yoga interventions have been used to decrease the risk of some chronic diseases such as cardiovascular disease (Holt, 2014) and multiple sclerosis (Oken et al., 2004) in various populations, including younger adults and the elderly (Evans, Lung, Tsao, & Zeltzer, 2012). Lab-based research has shown the benefits of undertaking yoga on body posture, balance, core strength, stability, flexibility and mental health of individuals of all ages (Cowen & Adams, 2005; Greendale et al., 2012; Ni et al., 2014; Pritha, 2009; Wang, Greendale, Kazadi, & Salem, 2012; Wang et al., 2013; Yu et al., 2012).

Yoga has also been shown to reduce mental stress by 5.9% (Hewett, Ransdell, Gao, Petlichkoff, & Lucas, 2011; Rocha et al., 2012; Sahay, 2007) and lower back pain by 11% (Brian & Cady, 2013; Crow, Jeannot, & Trewhela, 2015). Tran et al. (2001) found an average increase of 26% in muscular strength, 57% in muscular endurance and 6.5% in VO_2max after 8 weeks of yoga. Practising yoga techniques enhanced cognitive memory by 3% (Rocha et al., 2012), and auditory and visual reaction time by 16% (Begum, Kumaran, Venkatesh, & Kulkarni, 2012). Studies have demonstrated the ability of yoga not only to improve sports performance of athletes but to also reduce health conditions of non-athletes (Cushing, Braun, Alden C-Iayt, & Katz, 2018; Donohue et al., 2006; Oken et al., 2004; Tayyebi et al., 2011).

Although a number of studies have investigated the effects of yoga on athletes (Gawinski, 2012; Shiraishi & Bezerra, 2016; Tran et al., 2001), the review of the literature suggests there is little research on the effects of yoga on sprint performance, particularly on team sport athletes that undergo considerable collisions while playing. Thus it was hypothesised that a yoga intervention may improve the sprint performance of athletes by improving flexibility, body position, body alignment, and balance of the body.

Yoga may also help in the reduction of risk factors associated with preventable non-communicable diseases such as cardiovascular disease (Bansilal, Castellano, & Fuster, 2015; Huffman, 2014; Who, 2011). Researchers suggest that yoga has the potential to improve lifestyles by incorporating mindfulness, relaxation, and increasing physical activity levels (Sarraf-Zadegan et al., 2003) which may have a positive effect on cardiovascular and other common chronic diseases.

Despite the popularity of yoga, few researchers have investigated the association between yoga and health, particularly cardiovascular health. Therefore it was hypothesised that yoga may have a positive effect on individuals' cardiovascular health that may be independent of the increased physical activity that occurs with practising yoga.

2.2 Rugby

Rugby union is a field-based contact sport with a growing player base, with more than 9 million rugby union players registered worldwide, making it one of the most popular sports in England, Ireland, Australia, and New Zealand (World Rugby, 2017). While in New Zealand, more than 150,000 players registered in 2015, and the participation rate is on the rise as 156,000 players registered in 2018 (New Zealand Rugby Union, 2020).

Playing rugby competitively requires a combination of physical fitness components, including strength, speed and acceleration (Brooks. et al., 2005), as well as considerable technical and tactical skills. To perform at a high level in the modern game of rugby, players require physical qualities and must develop an optimal level of body composition together with anaerobic capacity, speed, power, and balance (Cunningham et al., 2016; Higham, Hopkins, Pyne, & Anson, 2014). In addition, high-performance rugby players are required to have rapid acceleration from a static position and fast and effective change in direction (Pienaar & Coetzee, 2013). Players are also required to be fast and strong to help with the high physical contacts and collisions during competition and training (Quarrie & Hopkins, 2007).

Elite rugby players participate in approximately 17 matches per year (approximately 30 weeks) and their exposure to the game varies depending on their allotted playing time (Quarrie et al., 2016). In the context of exposure to the training, it is important to consider physical conditioning, fatigue level and recovery time in relation to the physical health and performance of active rugby players (Quarrie et al., 2016). Apart from many anthropometrical and physiological components, body coordination and cognitive skills have been demonstrated to be key in sports performance (D. Van Biesen, 2018). Playing rugby often requires players to complete dual tasks, that is; running while simultaneously performing other tasks that require cognitive ability such as catching the ball, and avoiding or making tackles. Such dual tasks require players to have good postural control. Postural control is the ability of the player to regulate the movement of their body's centre of mass, under any postural perturbation. Several studies have also demonstrated that athletes who possess enhanced perceptual-cognitive skills and visual-search strategies perform better than their counterparts (Derek T. Y. Mann, 2007; R. Vaeyens, 2007). Thus, the assumption is that a decrease in postural sway may reflect an improvement of balance and perhaps improved balance potentially relates to enhanced sports performance.

There is a dearth of knowledge about how long-term interventions affect the balance, sprint performance and flexibility of rugby players. This research aims to determine if a yoga intervention designed to be implemented in their natural environment (alongside traditional training) may lead to improvements in sport-related performance measures such as sprinting ability and balance in rugby players. Specifically, it is not clear whether a yoga intervention, added to the usual rugby training procedures will improve balance and sprint performance of rugby players.

2.3 Balance in rugby players

Rugby is a multidirectional sport that requires players to continually re-adjust their body position while playing (i.e. running, avoiding / making tackles etc.). This ability to act according to the situation challenges the neuromuscular system (Horak, 2006), which requires players to deal with a rapidly changing game situation. Having a good balance allows rugby players to be in their most efficient position, react quickly, and reduce their response time (Chow et al., 2016; Matsuda, Demura, & Uchiyama, 2008). Balancing requires central and peripheral nervous systems to work together, along with agonist and antagonist muscles, to have better coordination when a player receives information during training and game situations.

Postural sway, or postural control or balance, is the ability to maintain a stable position while performing a task either in a static or a dynamic condition (Winter, Patla, & Frank, 1990). Previous studies have proposed that, with age, one's ability to use sensory information obtained from the visual, vestibular and other systems, and motor responses, decreases (Arampatzis, Peper, & Bierbaum, 2011; Grigg, 1994; Palmieri et al., 2003). Thus, one's ability to balance can diminish over time. However, balance should improve with balance training. A study on young professional gymnasts found that experienced gymnasts gained superior balance composite score percentage (91.6 ± 1.6), compared to untrained controls (83.3 ± 2.8, $P<0.001$) and adults (81.0 ± 2.3, $p<0.001$) by influencing their motor response strategy with repetitive training (Balter, Stokroos, Akkermans, & Kingma, 2004). However, some evidence in the literature suggests that improved balance with training is due to improvement in proprioceptive and visual cues (Ashton-Miller, Wojtys, Huston, & Fry-Welch, 2001). Interestingly, although researchers may not agree on the exact mechanism involved, there is consensus that exercise routines have a major influence on improving balance (Ashton-Miller et al., 2001).

To improve balance, correct sensory information is required from the visual, vestibular, proprioceptive, and tactile senses. This may better coordinate the neuromuscular system to control how the body works (Dunsky, Zeev, & Netz, 2017; Horak, 2006). Furthermore, different strategies are adopted by players to balance their bodies (Balter et al., 2004), which may affect a player's performance. Despite the fact that coaches and trainers often include various training components such as strength and flexibility into their training routines, what seems to be missing is the recognition of balance as a vital training component that may enhance performance and reduce injury incidences in rugby players.

Rugby players often perform or engage in many bouts of high-intensity activity, including running, jumping, kicking, and other quick, agile movements (Chow et al., 2016). A rugby player may also be required to have superior joint accelerations while running and kicking the ball or performing cutting manoeuvres during tackling or being tackled during the game. Since balance is important in many of the static and dynamic movements performed by rugby players (i.e. accelerating and sprinting), perhaps interventions that work to improve balance may help to improve performance in these performance areas.

2.3.1 Rugby performance

Given that rugby is a physically demanding game and a rugby player runs an average of 5 km during a game (Busbridge, Hamlin, Jowsey, Vanner, & Olsen, 2020), which includes many short sprints, speed is an indispensable component in determining the performance and success of a rugby player. To measure speed a rugby player is required to sprint distances (15 – 100 m) that are needed in a game situation. In rugby, players accelerate and sprint over short distances ranging from 10 – 20 m either to attack or defend the ball from the opponent. Previous research has indicated that a rugby player spends between 6 to 14 percent of their game time completing high-intensity activity, while sprinting time varies from 4 to 25 percent depending on the playing position (Busbridge et al., 2020; Duthie, Pyne, Marsh, & Hooper, 2006). Duthie et al. (2006) determined that achieving 0.5 m distance with a quicker acceleration will make a meaningful difference for a rugby player which will allow a player to catch an opponent or, alternatively, evade an opponent in attack.

Despite the fact that acceleration and speed are crucial for a rugby player during a game, few studies have investigated the effects of training interventions that focus on sprint performance improvement. The majority of researchers use traditional methods to increase strength and power of athletes (e.g. heavy lifting, plyometric s etc. (Harris, Cronin, Hopkins, & Hansen, 2008), but there are other ways to improve muscle function. For example, increasing the length of the muscle or improving the efficiency of the muscle by increasing joint flexibility (Boyle, Sayers, Jensen, Headley, & Manos, 2004; Gothe & Mcauley, 2015; Pauline & Rintaugu, 2011) can also be beneficial.

Therefore, to enhance sports performance, alternative training interventions have been developed by researchers to suit the individual's specific needs (James, Robertson, Haff, Beckman, & Kelly, 2016; Verrall, Kalairajah, Slavotinek, & Spriggins, 2006). For example, yoga interventions have been used to improve reaction time by 16% (Begum et al., 2012), posture (Brunelle et al., 2015) and motivation (Donohue et al., 2006), for athletes from long-distance running and skating to non-athletic populations. However, there is a lack of research investigating the effects of yoga on postural control in rugby players.

A good body posture also allows efficient movement, and yoga-based interventions have helped increase the postural and muscular movements in older and younger adults (Wang et al., 2012). Therefore, adopting a yoga-based intervention together with regular sports training in rugby players may help improve body posture and control and thereby performance.

2.4 Cardiovascular health

Yoga has been suggested to improve flexibility in general by approximately 3 cm or 11.5% (Amin & Goodman, 2014; Gawinski, 2012). It has been proposed that an improvement of 13% in flexibility will lead to a meaningful improvement in cardiovascular health (Cramer et al., 2014; Cramer, Sellin, Schumann, & Dobos, 2018; Ogston, Crowell, & Konowalchuk, 2016; Pauline & Rintaugu, 2011). Cardiovascular disease is the leading cause of death worldwide (Bansilal et al., 2015; Gersh, Sliwa, Mayosi, & Yusuf, 2010; Mathers, Vos, Stevenson, & Begg, 2001; Ministry of Health, 2009; Orszag & Emanuel 2010; Perk et al., 2012; Who, 2011). It is responsible for approximately 40% of all deaths in Europe and America (Mettauer et al., 2001; Perk et al., 2012). Similar trends are seen in New Zealand citizens, where every 90 min, one person dies due to a heart condition (Ministry of Health, 2015b). Cardiovascular disease is usually progressive in nature (Dzau et al., 2006), it also creates an excessive burden to the public healthcare system in New Zealand and globally (Ameratunga, Alexander, Smith, Lennon, & Norton, 1999; Leal, Luengo-Fernandez, Gray, Petersen, & Rayner, 2006; Ministry of Health, 2009, 2015b). However, if symptoms and risk factors of cardiovascular disease can be detected early, prevention strategies may be implemented to reduce the likelihood of the disease causing serious health consequences. High blood pressure, high cholesterol, smoking, diabetes, excessive body weight, depression, family history of CVD, poor diet, sedentariness and high-stress levels are major factors contributing to poor vascular health that results in CVD (Boreham et al., 2004; Ministry of Health., 2017; Nakamura et al., 2006; Pal, Singh, Chatterjee, & Saha, 2014; Yusuf et al., 2016).

Previous research has proven that high cholesterol and blood glucose levels increase the chances of developing cardiovascular disease (Yusuf et al., 2016). Researchers have found that yoga is effective in modifying some of the risk factors associated with mild hypertension, type 2 diabetes and dyslipidaemia (Mahajan, Reddy, & Sachdeva, 1999; Shantakumari, Sequeira, & El Deeb, 2013). Yogendra et al. (2004) found that patients with coronary artery disease reduced their total cholesterol by 23% and their LDL cholesterol by 26% after one year of yoga practice. Ramamoorthi, Gahreman, Skinner, and Moss (2019) in their meta-analysis reported that yoga reduced various cardiovascular risk factors including fasting blood glucose (FBG) [Standard Mean Difference (SMD -0.064 mg/dL (95% CI -0.201 to 0.074)]; low density lipoprotein (LDL) [SMD-0.090 mg/dL (95% CI -0.270 to 0.090)]; triglycerides [SMD -0.148 mg/dL (95% CI -0.285 to -0.012)]; total cholesterol [SMD -0.058 mg/dL (95% CI -0.220 to 0.104)] and systolic blood pressure [SMD -0.058 mm Hg (95% CI -0.168 to 0.053)] in a variety of population.

Regular physical activity is continuously regarded as one of the best and most cost-effective means to gain health benefits or maintain good health (Simon, 2018). People who participate in physical activity and sports are shown to have a higher level of fitness, which contributes towards improved health outcomes (Bhella et al., 2014; Lankhorst et al., 2015; Pharr & Lough, 2016; Woolf & Bisognano, 2011). Yoga has gained in popularity with more than 300 million people regularly practising yoga around the world. A recent report from Sport New Zealand (2020), found that yoga participation was growing and expected to increase further in coming years. A major benefit of regular physical activity is improvements to the vascular system, by improving endothelial function and increasing nitric oxide (Di-Francescomarino, Sciartilli, Di-Valerio, Di-Baldassarre, & Gallina, 2009; Sandoo, Van Zanten, Metsios, Carroll, & Kitas, 2010), or by altering the elastic properties of smooth muscle and/or connective tissue which determines arterial stiffness (Vlachopoulos, O'rourke, & Nichols, 2011).

Arteries lose their elasticity with increasing age (Tanaka, Desouza, & Seals, 1998), and evidence suggests that reduced arterial compliance associated with age amplifies the risk of cardiovascular disease and other heart-related diseases (Cortez-Cooper et al., 2008; Mattace-Raso et al., 2010). Increased arterial stiffness is not only responsible for cardiovascular disease but also is a marker for various other health risks, including heart failure, as well as stroke, dementia, and renal disease (Zieman, Melenovsky, & Kass, 2005). Studies have shown that the elasticity of the arteries can be reversed by including moderate-intensity physical activity (Asmar et al., 2001; Boreham et al., 2004; Butlin & Qasem, 2017; Cortez-Cooper et al., 2008; Coutinho, Gomes, Franca, Oishi, & Salvini, 2004; Douris et al., 2013; Goenka & Lee, 2017; Laurent et al., 2006; Lear et al., 2017; Myers et al., 2015; Pal et al., 2014; Patil, Aithala, & Das, 2015; Scheuer & Tipton, 1977; Vlachopoulos et al., 2011).

2.4.1 Aging

Age is a major risk factor for cardiovascular disease and arterial stiffness (Alghatrif et al., 2013; El Feghali, Topouchian, Pannier, & Asmar, 2007). The Baltimore longitudinal study by Alghatrif et al. (2013) found a proportional increase with increasing age in the pulse wave velocity (a measure of arterial stiffness) in individuals after the age of 40. Previous lifestyle and exercise intervention based studies have also shown that lifestyle and physical activity-based modifications have the potential to reduce the impact of aging on arterial stiffness (Cortez-Cooper et al., 2008; Nowak, Rossman, Chonchol, & Seals, 2018). However, whether practicing yoga (a form of stretching exercise) can also be beneficial in reducing the effect of aging on arterial health is yet to be researched.

2.4.2 Sex

Like age, sex is another factor that plays a significant role in predicting the cardiovascular health of individuals. Previous studies have shown that women tend to have lower arterial stiffness compared to their male counterparts (Ahimastos, Formosa, Dart, & Kingwell, 2003; Tanaka et al., 1998) until menopause (Wong, Sanchez-Gonzalez, Kalfon, Alvarez-Alvarado, & Figueroa, 2017). An increase in arterial stiffness is observed in both sexes during aging, however, during adulthood, it is slower in women compared to men (Alghatrif et al., 2013). Although, during puberty, the arterial stiffness increases in men, whereas it is maintained or improved in women (Ogola et al., 2018). The change in the arterial stiffness seen during puberty and adolescence usually disappears in the sexual dimorphism after menopause (Benjamin et al., 2017). Therefore, postmenopausal women have stiffer arteries than aged-matched men. Clearly, arterial stiffness affects the aging individuals of both sexes. However, it is currently unknown whether yoga acts differently in men and women in terms of improving cardiovascular health.

2.4.3 Resting heart rate and heart rate variability

Previous researchers have demonstrated age and sex influences heart rate and heart rate variability, a predictor of future cardiovascular health events (Kuo et al., 1999). HR and HRV provide a measure of how the organism reacts and adapts itself to various changes related to stress such as physical fatigue and metabolic demand due to an activity (Maranesi et al., 2016).

Previous studies have confirmed that resting heart rate is an independent predictor of cardiovascular disease. The intrinsic heart rate is generated by the sinoatrial node in the absence of any neural or hormonal influence (Sessa et al., 2018). Furthermore, the resting heart is determined by the activity of the parasympathetic nervous system and the sympathetic nervous system (White & Raven, 2014). Resting heart rate normally ranges between 70 – 75 beats per minute however this range may vary in trained or physically active individuals (Kalsbeek et al., 2007).

When there is a fluctuation in the duration and time of the heartbeat, this variability between beats is called heart rate variability (Cygankiewicz & Zareba, 2013). Heart rate variability evaluates the variation in the beat-to-beat intervals in the heart rhythm, which reflects parasympathetic (vagal) and sympathetic actions on the sinus node. Heart rate variability is a marker used to predict future incidents of cardiovascular disease, as it is a standard non-invasive method for evaluating autonomic nervous system (ANS) function (Messina et al., 2012). Reduced heart rate variability, reflects sympatho-vagal imbalance (reduced vagal activity), and is associated with increased cardiovascular health risk, while increased heart rate variability is associated with reduced cardiovascular health risk (Dekker et al., 2000; Schroeder et al., 2003; Soares-Miranda et al., 2014). Based on these associations between heart rate variability and sympatho-vagal balance in the autonomic control of the heart, we can use heart rate variability as an indication of the overall ANS control. However, whether yoga has any effect on heart rate, heart rate variability, and arterial stiffness is yet to be researched in detail.

2.4.4 Blood lipid and glucose profile

Cardiovascular disease can be indicated by measuring the blood lipid profile of individuals. Various epidemiological studies have reported positive associations between high levels of low-density lipoprotein cholesterol, triglycerides and decreased high-density lipoproteins and risk of cardiovascular disease. The desired clinical levels for these lipids are shown in Table 1 (Boullart, De Graaf, & Stalenhoef, 2012; Dayimu et al., 2019; Jellinger et al., 2012).

Table 1. Desired clinical blood lipid levels.

Total cholesterol:	Less than 200 mg/dL = Desirable
	200-239 mg/dL = Borderline high
	240 mg/dL and above = High
HDL cholesterol:	Below 40 mg/dL = Suboptimal (Low)
	60 mg/dL and above = Optimal (High)
LDL cholesterol:	Less than 100 mg/dL = Optimal
	100-129 mg/dL = Near/above optimal
	130-159 mg/dL = Borderline high
	160-189 mg/dL = High
	190 mg/dL and above = Very high
Triglycerides:	Less than 150 mg/dL = Normal
	150-199 mg/dL = Borderline high
	200-499 mg/dL = High
	500 mg/dL and above = Very high

Change in blood lipid profile has been associated with future events of cardiovascular disease. Yoga intervention based studies have shown a reduction in the blood lipid profile of individuals (Cramer et al., 2014; Patil et al., 2015).

In addition to blood lipids, blood glucose levels have also been associated with health problems in, particular metabolic diseases including diabetes. The desired blood glucose levels are shown in table 2. To manage and blood glucose levels successfully, its management revolves around various lifestyle factors such as reduced smoking, increased physical activity, reduced sedentariness and consuming a healthy diet. While yoga is a form of exercise, the effects of yoga specifically on blood glucose has not been extensively researched.

Table 2. Desired blood sugar levels

Target Levels by Type	Upon waking	Before meals (pre-prandial)	At least 90 minutes after meals (post prandial)
Non-diabetic*		4.0 to 5.9 mmol/L or 72 to 99 mg/dL	under 7.8 mmol/L or 140 mg/dL
Type 2 diabetes		4 to 7 mmol/L	under 8.5 mmol/L
Type 1 diabetes	5 to 7 mmol/L	4 to 7 mmol/L	5 to 9 mmol/L
Children w/ type 1 diabetes	4 to 7 mmol/L	4 to 7 mmol/L	5 to 9 mmol/L

Adapted by (Dibetesuk, 2019)

Although exercise is a viable option for most people and guidelines for the recommended amount of exercise are provided by the New Zealand government (Ministry of Health, 2015a), there are also individuals who cannot complete the recommended amount of daily exercise (30 min) or for whom many exercise methods are inappropriate (i.e. injured, overweight, or unable to engage in any physically demanding activities). Yoga has been one of the most preferred physical activities that New Zealand residents undertake (Sport New Zealand, 2015, 2016) which may offer significant health benefits, especially for those that cannot undertake traditional exercise (e.g. walking, swimming, running etc).

Yoga is very popular in western cultures (Van Puymbroeck, Payne, & Hsieh, 2007), but a lack of quality scientific studies on yoga prevents it from being prescribed more widely by medical practitioners. One drawback of the extant literature is that most of the studies have been conducted in Indian populations, which may reduce its generalisation and dissemination of results to the western world (Innes, Bourguignon, & Taylor, 2005). Also, the majority of these studies have methodological weaknesses, including poorly described research methods, small cohorts, insufficient statistical analysis, either no or inappropriate control groups, and inclusion of multiple interventions (Innes et al., 2005). Considering the possible beneficial effects of yoga on cardiovascular health, there have been few well-controlled cross-sectional studies investigating the influence of yoga on clinical outcomes such as arterial stiffness and blood pressure in the western world (Cramer et al., 2018; Miles et al., 2013; Patil et al., 2015).

Therefore, one purpose of this thesis was to investigate associations between clinical measures of cardiovascular health, including pulse wave velocity, blood pressure, and augmentation index, among a group of volunteers who regularly practice yoga with those that do not practice yoga in New Zealand.

2.5 Yoga intervention

Various studies have reported physical, physiological, and psychological health benefits of yoga practice (Cowen & Adams, 2005; Cramer et al., 2018). The yoga intervention used in these studies aimed to develop balance, flexibility, joint stability, and control and improve the overall physical development of players. Distefano (2016) reported a six-week injury prevention intervention improved military freshmen's fitness and movement techniques in the U.S. However, these changes were not long-lasting and disappeared after eight months. Thus, for long-term benefit and continued improvement, an exercise intervention should sit alongside the individual's actual physical training (Distefano, 2016). Yoga interventions have helped athletes improve their physical health and sport performance (Polsgrove, Eggleston, & Lockyer, 2016; Shiraishi & Bezerra, 2016) when they have been conducted over 6 to 10 weeks (2 to 3 times per week). Based on the length of the intervention used by previous studies, in this thesis, a relatively long yoga intervention (one 8-week, and two 12-week) was used to accompany normal rugby training routines. The aim was to get the best possible performance results while complementing rather than encroaching on the existing sport training. Therefore, Yoga classes were conducted by a registered yoga exercise professional (NZ), who also adapted the intensity of asana and their execution to the needs and abilities of the players.

The yoga intervention used in studies in this thesis (chapters 3, 4, and 5) was exclusively designed for athletes based on previous overall exercise recommendations (Cassell, Kerr, & Clapperton, 2012; Distefano, 2016; Green et al., 2009; Hood, Liguore, Moore, Pflibsen, & Meshul, 2016; Hopkins, Marshall, Quarrie, & Hume, 2007; Kara, 2012; Mikkelsen et al., 2014; Quarrie, Hopkins, Anthony, & Gill, 2013; Williams et al., 2016) and was adapted in terms of duration according to the time availability of the athletes and our knowledge of subsequent physiological adaptations. The yoga intervention was designed to be simple and easy so that it could be performed anywhere and anytime, and provide opportunities for players to practice the intervention during the offseason if desired. Most information used in these interventions is widely and freely available in yoga texts as well as on the worldwide web. (Dennis, Finch, Mcintosh, & Elliott, 2008; Green et al., 2009; Williams et al., 2016).

Chapter 3

Effects of a 12 week yoga intervention on postural sway in male rugby union players.

3.1 Preface to study 1:

Study 1 had both a practical and an academic purpose. Preparing a small study was useful as it allowed the researcher to trial the recruitment protocols, participant management systems, and test the possibility of including yoga with regular rugby training. Accordingly, study 1 was designed to investigate the use of regular yoga practice (which complimented normal rugby practice), for improving the balance of male rugby union players.

Authorship:

Tilak Raj, Catherine Elliot, Michael J. Hamlin

Faculty of Environment Society and Design, Department of Tourism, Sport & Society, Lincoln University, New Zealand.

3.2 Abstract

In an attempt to reduce the risk of injury that accompanies poor balance, many strength and conditioning coaches and trainers incorporate balance and postural control training into players' training regimes. However, relatively few balance interventions involve yoga. Therefore, the purpose of this study was to evaluate the effect of a modified yoga programme on postural sway in rugby union players. Twenty-nine male rugby union players were ordered based on their 5 m performance and then randomly (19 ± 1.3 years old, mean ± SD) assigned to two groups: a yoga group (YG, n =15), which practised yoga for one hour, two times a week alongside their regular 90 min two times a week rugby training, 80 min weekly game time, and 120 min of strength and conditioning time, and a control group (CG, n =14), which only participated in their standard 90 min two times a week rugby training, 80 min weekly game time, and 120 min of strength and conditioning training. Postural sway was measured during various 30s balance activities at baseline (pre-season) and at the end of the 12 week playing season (post-season) on a force platform. The yoga group showed a significantly reduced sway signal in the 2-legged eyes closed balance test in the antero-posterior (-109.7% ± 82.9 mean ± 95% CI, $p < 0.005$) and medial-lateral (-115.5% ± 92.1 $p < 0.005$) directions. However, no significant change between-groups was found in the 1-legged eyes closed or 1 or 2-legged eyes open balance tests. Results suggest that practising yoga may reduce postural sway in specific directions which may improve balance in rugby union players.

Keywords**:** Exercise; proprioception; sports performance; balance training.

3.3 Introduction

Rugby union is a field-based contact sport with a growing player base of approximately 9.1 million players registered worldwide, making it one of the most popular sports in England, Ireland, Australia, and New Zealand (World Rugby, 2017). Rugby players are typically strong and engage in many bouts of high-intensity activity including running, jumping, kicking, and other quick, agile movements (Chow et al., 2016). The fast pace and physical contact in rugby makes it essential that players are able to quickly control posture and return to a steady position when exposed to balance perturbations (Matsuda et al., 2008). In addition, rugby players need to maintain a stable posture for the safe execution of efficient and effective movements (Horak, 2006; Mcclay et al., 1994). Therefore, better postural stability, or improved balance, plays a vital role in rugby players' performance.

Rugby is dynamic in nature, and rugby players are required to actively balance their body weight depending on the game situation (Chow et al., 2016). As part of the game, rugby players tackle opposing players to gain possession of the ball, or are occasionally required to kick the ball while running, which necessitates good balance, sometimes on one leg as well as in compromising positions (Matsuda et al., 2008). To control posture a player must maintain control of their centre of gravity by remaining as close to the centre as possible using hip and ankle balance strategies (Cherng, Hsu, Chen, & Chen, 2007). If the change in the centre of gravity is large, due to either inappropriate neuromuscular strategies selected by the player or an impaired ability to use the sensory feedback efficiently, the player may develop impaired balance and increased postural instability (Horak, 2006), which have been associated with an increased risk of injury (Hrysomallis, 2007).

Postural sway is a method of observing the sway of a player's centre of pressure (COP) displacement and body weight distribution and can be used as a measure of balance (Chagdes et al., 2016; Morasso, Spada, & Capra, 1999). To reduce postural sway, an efficient sensory-muscular feedback response is required (Chagdes et al., 2016; Guskiewicz, 2003). Any delay or inattention to this response may increase postural sway, particularly in the anterior-posterior and medial-lateral planes, which may result in undesired movement patterns, which could affect a player's performance (Guskiewicz, 2003; Talarico et al., 2017). The yoga used in this study, is an ancient Indian system involving various static and dynamic stretching positions, as well as breathing, and relaxation techniques. It is progressive in nature and low-cost, requiring only a trained yoga teacher and no specialised equipment. While yoga has been shown to improve balance in older adults, (Nick, Petramfar, Ghodsbin, Keshavarzi, & Jahanbin, 2016; Schmid et al., 2010), little research has addressed the contribution of yoga towards enhancing the balance of rugby union players. This study is designed to determine the effects of a 12 week yoga intervention on single- and double-legged postural sway of male rugby union players.

3.4 Methods

A yoga intervention was specifically designed for rugby players and delivered by a yoga instructor (registered exercise professional, New Zealand). All participants were in the same yoga class, and all sessions were completed in a large open fitness room. The centre of pressure (COP) is evaluated by collecting the raw data on the magnitude of the force signals applied from the player's body through his feet in the anterior-posterior, and the medial-lateral, directions. COP is also derived from the data collected in the vertical direction on the force platform. To assess postural sway, the movement of the COP is computed by calculating the pressure applied in the direction of the action, and then the system measures the associated pressure underneath the foot of the player on the platform. The mean velocity of the raw signal received in anterior-posterior, medial-lateral, and vertical directions, and a combination of all, were used to assess postural sway using COP (Black, Wall, & O'leary, 1978).

During the intervention, players spent the first 10 min performing a set of 12 dynamic stretching postures used as a warm-up (sun-salutation sequence), an easy to follow routine to standardise the practice throughout the study. Players then performed 17 sets of 30 s stretches focussing on quadriceps, hamstring, calves in five different postures, three postures with 13 sets of 20 s stretches focusing on the hamstring, 17 sets of 10 s stretches focussing on gluteal and lower back area in eight postures, 10 sets of 15 s stretches focussing on shoulders, upper-back, and abdominal area in six postures, 4 sets of 15 s stretching focussing on the middle back in four posture, and 4 sets of 20 s stretching focussing on hip abductor and hip adductors in two postures. The postures performed during the intervention are typically a combination of joints and muscles. Total time spent on stretches amounted to 35 ± 2 min (mean ± SD) at each yoga session. Players spent approximately 25 ± 3 min performing dynamic stretching, which included 10 min of sun-salutation practice, and around 12 - 15 min in both dynamic and static stretching postures. Players were also required to complete 10 min of mindful relaxation or mental recovery (Savasana) at the end of each session.

3.5 Exclusion criteria

Any subject who had any current or previous injury or medical condition that does not allow them to perform yoga postures or the various fitness tests.

3.6 Participants

The current study used a systematic random sampling method to recruit the rugby players from a local rugby union football club. A spreadsheet was used to calculate the number of participants required in the study with the smallest worthwhile change in performance being 1.0% and the typical error or within-subject SD in similar tests of 0.7%. Using a type 1 error of 0.5% and a type 2 error of 25% the number of participants in a pre-post parallel-groups controlled trial was calculated to be 7 per group. Twenty-nine male club-level rugby union players (19.0 ± 1.3 years, mean ± SD) volunteered to participate in the study and were ordered based on their 5-m sprint performance and then were divided into two groups using systematic random sampling method (i.e. the fastest 2 players were randomly assigned to either the yoga or control group, then the next 2 fastest players were again randomly assigned to the groups etc.). This was to balance the two groups in terms of performance. The yoga group (YG n =14) that practised yoga for one hour two times a week in addition to 90 min two times a week rugby training, 80 min weekly game time, and 120 min of strength and conditioning time, and a control group (CG n =15) that completed their 90 min two times a week rugby training, 80 min weekly game time, and 120 min of strength and conditioning time without yoga (Table 3) During the study, players were asked to refrain from physical activities such as heavy single leg weight lifting or balance training in the gym that might affect balance, with the exception of those provided by their strength and conditioning coach. All players completed a medical questionnaire (Physical Activity Readiness Questionnaire) and reported no contraindications to engage in maximal exercise. All players were also informed about the possible risks of volunteering for this study and provided written informed consent prior to the study. Following the Declaration of Helsinki, this research was approved by the Lincoln University Human Ethics Committee (HEC approval number 2017-14).

3.7 Yoga intervention

A registered yoga instructor led the 60 min yoga intervention classes twice a week for 12 weeks, with the intervention starting at the beginning of the rugby season. Each yoga session consisted of a warm-up of 10 min (Surya-namaskar: a dynamic stretching sequence of postures), followed by 35 min of yoga postures (10 min standing, 10 min sitting, and 15 min of supine and prone postures and a mix of static and dynamic postures), and 10 min relaxation in the final resting position (lying in the supine position without any stretching exercise), plus 5 min allocated for transitions between postures. The sessions consisted of 32 yoga postures (including standing, sitting, forward bending, backward bending, spinal twist, core engagement and body inversion) targeting the major muscle groups of the body (e.g., gastrocnemius, hip flexors, hip extensors, abdominals, and trapezius). Basic breathing and relaxation techniques were taught in the first 2 weeks of the intervention. After the initial session players practised these two techniques for the remaining six weeks. The yoga postures were modified to improve the range of motion, and promote the progression of difficulty and intensity with the support of yoga props (such as blocks, straps, or ropes), with the aim that movements were performed as accurately as possible without inducing pain beyond that experienced in stretching.

Table 3. Baseline characteristics of the players.

Characteristics	Yoga Group (*n* =15)	Control Group (*n* =14)
Age)y(	19.0 ± 1.3	19.0 ± 2.0
Height)cm(	181.3 ± 8.4	182.7 ± 4.2
Weight)kg(	88.9 ± 18.7	85.5 ± 9.8
BMI)kg·m^{-2}(	26.9 ± 4.8	25.6 ± 2.8

Data are mean ± SD.

3.8 Postural sway measurement

Data were collected over a 30 s period with a sampling frequency of 100 Hz, in the morning between 0900 - 1200 using a force platform which amplifies, filters, and digitises the raw signals from the strain gauge amplifiers inside the force plate (Bertec Corp, Columbus, OH). The resulting output is a six-channel 16-bit digital signal containing the forces and moments in the x, y, and z axes. The digital signals were subsequently converted via an external analogue amplifier (AM6501, Bertec Corporation). The initial centre of pressure signals were calculated with respect to the centre of the force-plate before normalization. Data were collected on two occasions (baseline and after the 12 week intervention).

The players were instructed to stand normally on the force platform barefoot, with feet in the centre of a marked area and their arms hanging by their side. While standing on the force platform, players were asked to concentrate on a fixed spot on the wall in front of them and to maintain their balance as much as possible (or to maintain balance for as long as possible in the eyes closed test). The data was collected once players said they were comfortable with their standing position. Each leg was tested (right, left, and 2-legged) and the order of tasks was randomly allocated. During testing, the subjects were asked to complete the following tasks: 1-legged stance with eyes open (right and left leg), a 2-legged stance with eyes open and eyes closed. Each position was held for 30 s and subjects were given a 1 min rest between each task, where they chose to either sit or stand and were allowed to drink water. The measurement took approximately 5-6 min for each player to complete. All players were required to not perform any strenuous exercise for 24 hours prior to testing. The testing was completed at the same time of day under similar climatic conditions for both testing days.

Table 4. Variation in the force signal during various balance tests before and after 12 weeks of yoga in the yoga and control groups and the between group differences.

Balance markers	Control group Baseline	Control group 12 week Post	Yoga group Baseline	Yoga group 12 week Post	Pre-post between group differences (%) Mean ± 95%CI
One-legged Right Leg Eyes Open					
Medio-lateral	23.11 ± 11.22	25.84 ± 11.27	19.37 ± 8.47	78.22 ± 158.53	-84.0% ± 155.4
Antero-posterior	16.92 ± 1.98	19.59 ± 4.95	15.99 ± 4.70	102.48 ± 244.45	-69.1% ± 143.6
Vertical	8487.68 ± 1133.08	8595.96 ± 1176.30	8501.80 ± 1797.74	8608.27 ± 1536	-133.4% ± 289.2
Medio-lateral COP	0.48 ± 0.64	0.52 ± 0.25	0.64 ± 0.29	0.46 ± 0.36	15.4% ± 246.9
Antero-posterior COP	0.26 ± 0.18	0.28 ± 0.12	0.31 ± 0.17	0.20 ± 0.14	-48.2% ± 269.6
One-legged Left Leg Eyes Open					
Medio-lateral	12.96 ± 20.52	26.18 ± 20.66	21.77 ± 8.78	87.74 ± 154.48	-59.5% ± 90.2
Antero-posterior	12.75 ± 10.15	23.55 ± 18.33	15.12 ± 6.96	103.68 ± 244.00	-39.2% ± 68.3
Vertical	8445.96 ± 1105.44	8597.68 ± 1170.86	8525.15 ± 1795.88	8622.15 ± 1527.42	-101.7% ± 277.7
Medio-lateral COP	0.44 ± 0.23	0.50 ± 0.27	0.48 ± 0.30	0.35 ± 0.21	83.1% ± 274.1
Antero-posterior COP	0.23 ± 0.14	0.20 ± 0.13	0.28 ± 0.18	0.21 ± 0.12	-14.5% ± 273.8
Two-legged Eyes Open					
Medio-lateral	8.93 ± 3.13	11.89 ± 8.66	12.60 ± 8.19	72.58 ± 160.25	-64.2% ± 90.0
Antero-posterior	12.92 ± 5.41	11.87 ± 2.91	7.82 ± 2.41	94.88 ± 246.11	-62.7% ± 80.5
Vertical	8501.95 ± 1132.46	8610.20 ± 1177.00	8521.15 ± 1801.72	8614.12 ± 1534.24	-141.9% ± 221.5
Medio-lateral COP	0.06 ± 0.15	0.10 ± 0.08	0.20 ± 0.21	0.13± 0.13	-38.7% ± 58.4
Antero-posterior COP	0.28 ± 0.24	0.23 ± 0.20	0.35 ± 0.19	0.39 ± 0.16	-45.8% ± 97.1
Two-legged Eyes Closed					
Medio-lateral	8.93 ± 3.13	16.21 ± 12.85	11.49 ± 7.75	73.23 ± 161.68	-115.5% ± 92.1*
Antero-posterior	12.92 ± 5.41	15.18 ± 4.73	12.22 ± 6.05	97.71 ± 247.43	-109.7% ± 82.9*
Vertical	8501.95 ± 1132.46	8610.10 ± 1180.49	8518.17 ± 1800.05	8606.73 ± 1530.69	-175.7% ± 197.7
Medio-lateral COP	0.32 ± 0.16	0.25 ± 0.19	0.13 ± 0.08	0.14 ± 0.09	-33.7% ± 242.1
Antero-posterior COP	0.07 ± 0.13	0.14 ± 0.14	0.35 ± 0.17	0.33 ± 0.12	-113.4% ± 281.4

Data are scaled up by 10 to increase readability; Data are mean ± SD of each group and the difference between groups given as the percent mean difference ± 95% confidence interval. * Statistically significant between groups ($p < 0.05$). COP, Centre of pressure.

3.9 Data analysis

Data were collected from the force platform which included movement in: antero-posterior, medial-lateral, and vertical directions, and also included centre of pressure in anterior-posterior and medial-lateral directions. Data were exported to Microsoft Excel and analysed using R studio (2019) (Boston, MA, USA). To analyse the raw data, a protocol described by Önell (2000) was employed. Firstly, the players' body mass was normalised with the signal collected. To remove the body oscillations due to the heartbeat, the signal was sent through a 4th-order Butterworth high pass filter with a cut-off frequency of 0.1 Hz. The signal was also low pass filtered with a cut-off frequency of 15 Hz to reduce measurement noise to remove slow drifts in the signal which are not directly associated with spontaneous sway. The standard deviation of the mean of each 30 s signal was used as an indicator of postural sway variability. A total of 9 measures were recorded. Since data were normalised with mass of the player, the mass signal was removed from the analysis. The following measures were used for the final analysis: the standard deviation (SD) of the antero-posterior, medial-lateral, and vertical, directions and centre of pressure in antero-posterior and medial-lateral directions. The data presented are the mean and the standard deviation of each task within the group (Table 4). The between-group percentage change from baseline to post-intervention was then calculated. Changes within and between groups were estimated using a mixed modelling procedure (Proc Mixed) in the Statistical Analysis System (Version 9.3, SAS Institute, Cary, North Carolina, USA) with an alpha level of 0.05.

3.10 Results

The average yoga session attendance rate was 21 sessions (75%), with 5 players attended all 24 sessions and 3 players attended only 16 sessions (60%). No player missed two consecutive sessions. Compared to the control group, the yoga group that incorporated 12 weeks of yoga into their rugby training routines had a significantly reduced postural sway in the 2-legged eyes closed antero-posterior -109.7% ± 82.9 and medial-lateral -115.5% ± 92.1 (mean ± 95% CI, $p < 0.005$) directions

(Table 4). The yoga group demonstrated, in most cases, non-significant decreases in postural sway in a number of balance markers in all stance conditions (right leg eyes open, left leg eyes open, both legs eyes closed, both legs eyes open), when compared to the control group (Table 4).

3.11 Discussion

Findings of this study suggest that 12 weeks of practising a standard yoga routine twice weekly for one hour in addition to normal rugby training can maintain or may improve postural sway in male rugby union players. The improvement was particularly prevalent in the antero-posterior and medial-lateral directions in the 2-legged eyes closed stance. Although there were no significant differences in the other sway characteristics of either 1-legged or 2-legged stances, the yoga group mostly showed improvements in all balance measures (18 out of 20 measures collected), when compared to the control group. The results of this study support previous findings indicating that regular yoga practice may decrease postural sway and improve balance (Ikai et al., 2013; Mondal, Majumdar, Pramanik, Chatterjee, & Darmora, 2017; Youkhana, Dean, Wolff, Sherrington, & Tiedemann, 2016). The yoga group also had the lowest signal magnitude in the vertical direction in all standing positions, suggesting a more stable stance than the control group. This reflects reduced underfoot activity and improved perceptual-motor skill, allowing the player to maintain a steady position (Stins, Michielsen, Roerdink, & Beek, 2009).

In this study, the yoga intervention integrated a series of mind-body exercises together with breathing, alignment, relaxation, flexibility and stretching as used by previous researchers (Gatts & Woollacott, 2006; Rogers, Fernandez, & Bohlken, 2001; Stoller, Greuel, Cimini, Fowler, & Koomar, 2012). Practising mind-body exercises are reported to improve balance significantly (Fiori, David, & Aglioti, 2014; Fong et al., 2016; Gatts & Woollacott, 2006; Stoller et al., 2012) Gatts and Woollacott (2006) reported that Tai-chi, a routine similar to yoga, improved neuromuscular activation in older adults when compared to a control group that did not practice Tai-chi.

There is mounting evidence that an efficient musculo-skeletal system improves muscle proprioception which may result in improved balance (Fiori et al., 2014; Horak, 2006; Mcclay et al., 1994; Proske & Gandevia, 2012; Stoller et al., 2012). It has been reported that yoga helps individuals to improve their balance, enhance feedback from the muscles and tendons surrounding the joints (Burke-Doe, Hudson, Werth, & Riordan, 2008), and reduces underfoot activity (Stins et al., 2009). However, none of the above measurements were taken in our rugby players, thus it is difficult to confirm the effect of yoga on any of these variables.

Previous research has also indicated that balance training with eyes closed may also have a positive effect on the vestibular system (Ledin, Kronhed, Möller, & Möller, 1990). Performing balance tasks without visual feedback increases the reliance on the somatosensory stimuli (Prado, Raso, Scharlach, & Kasse, 2014) which may have an effect on the balance of the rugby players of the current study. Since the significant improvement was observed in the eyes closed condition, it is possible that the inclusion of postures with eyes closed (as in some of the postures in the yoga group of this study) may have improved neural and sensory feedback systems of the yoga group, thereby increasing sensitivity to somatosensory and vestibular feedback which may have improved balance and reduced postural sway in the yoga group. In conclusion, practising yoga for 12 weeks only reduced postural sway significantly in the antero-posterior and medial-lateral directions in the two-legged eyes-closed balance task of the yoga group. It is unclear why the changes were observed in the two-legged eyes-closed task and not in the other measures tested. Hence the overall effect of yoga on 1-legged and 2-legged eyes open balance tasks remains speculative until further research can consistently show a positive effect on players balance.

3.12 Limitations

In the current study, only male players were contacted to participate in the study, therefore the application of these results is limited to males and further research is required to investigate the possible effects on females. The fact that all players were from the same club means that the intervention practised and information provided to the yoga group may have also reached the control group, and some control subjects may have practised the intervention without the knowledge of the researcher. The study could have been improved with a larger sample size, or a crossover design with sufficient time for washout of effects. Due to the academic time commitments of players over the season (all players being full-time university students), the attendance rate of some players was only 60%, which may have affected the results of the study. Perhaps if the participation rate of the players was higher and they spent more time practicing yoga we may have produced more adaptations and a bigger overall change in balance parameters in the yoga group. Future studies may also look for ways to engage the participants such as by giving them information booklets or making content available online for them to practice at their own discretion. Finally, while the sway significantly reduced in the 2-legged eyes-closed test for the yoga group, the relevance of an eyes-closed balance test to balance control during a rugby game (with eyes open) is unknown. Hence, the results will remain exploratory until a more thorough longitudinal study is conducted on a larger sample with more applied balance tests for rugby players.

Chapter 4

The effects of an eight week yoga intervention on hamstring flexibility and sprint performance of male rugby players.

4.1 Preface to study 2:

The results from study 1 (chapter 3) indicated a beneficial effect of yoga on postural sway and balance in eyes closed circumstances among male rugby players. Therefore, it was suspected that there may be a positive effect of yoga on sprinting performance since this requires balance and coordination. In addition, the rugby players who completed 12 weeks of yoga training (as in study 1) recognised that it was time-demanding, with a number of participants complaining due to competing demands on their time. Therefore, in study 2, a similar yoga intervention was used with reduced time demand on the participants to 8 weeks of yoga classes in the hope that the attendance rate would be high.

Authorship:

Tilak Raj, Michael J. Hamlin, and Catherine Elliot

Faculty of Environment Society and Design, Department of Tourism, Sport & Society, Lincoln University, New Zealand.

4.2 Abstract

The purpose of this study was to evaluate the effect of a structured yoga intervention on flexibility and sprint performance in male rugby union players. Players were randomly a yoga group that practised yoga for 1 hour two times a week for eight weeks in addition to their normal rugby training, or a control group with regular rugby training but no yoga intervention. Data was collected during pre-season and mid-season on hamstring flexibility (sit and reach test) and sprint performance (measured at 5, 10, and 30 m). Statistical analyses were performed using SPSS. The yoga group showed a small non-significant decrease (-1.2% ± 21.4, $p = 0.05$) in hamstring flexibility compared to the control group which demonstrated a large significant decrease (-14.8% ± 23.7) (mean % change ± 95% CI, $p < 0.05$). The yoga group also showed minor non-significant improvements faster sprint times -3.2% ± 10.4, -0.7% ± 9.0 for the 5 and 10 m sprints split times respectively (mean % change ± 95% CI) compared to controls -0.4% ± 10.2, 0.4% ± 7.9. Results indicate that an 8 week yoga intervention was able to minimize the loss of hamstring flexibility among rugby union players compared to a control group. However, while there was minimal loss in flexibility in the group practising yoga, sprint performance was not significantly altered between groups.

Keywords – Performance, range of motion, acceleration, stretching

4.3 Introduction

The increased professionalism of sport, particularly rugby, in the past few decades has coincided with an increased research interest in flexibility and its effects on athletic performance (Campbell, Peake, & Minett, 2018). Flexibility is a vital factor that has been associated with improved performance (Fletcher & Anness, 2007; Fletcher & Jones, 2004) and reduced sports-related injuries (Shellock & Prentice, 1985). Many coaches, physicians, and trainers have accepted the important role flexibility plays in sports and have included exercises to increase and maintain flexibility in warm-up sessions prior to sports activity (Fletcher & Anness, 2007; Guiser, 2017). However, others remain unconvinced of the beneficial effects of flexibility training (Sayers, Farley, Fuller, Jubenville, & Caputo, 2008).

Researchers have reported mixed results when examining the effects of flexibility on speed, gait cycle, athletic performance and countermovement jump performance (Bradley, Olsen, & Portas, 2007; Favero, Midgley, & Bentley, 2009; Fletcher & Anness, 2007; Fletcher & Jones, 2004; Jaramillo, Boolani, Jacobson, & Hill, 2013; Lima, Ruas, Behm, & Brown, 2019; Paradisis et al., 2014; Perrier, Pavol, & Hoffman, 2011; Sayers et al., 2008; Shrier, 2004; Skaggs, Joiner, Pace, Sini, & Skaggs, 2015; Yuktasir & Kaya, 2009; Živković & Lazarević, 2011). These mixed results have created confusion and debate among researchers about the role flexibility plays in sport performance, particularly around the association stretching has with subsequent explosive performance (Dintiman, 2013; Gleim & Mchugh, 1997; Paradisis et al., 2014; Sayers et al., 2008; Shrier, 2004).

For example, Nelson, Driscoll, Landin, Young, and Schexnayder (2005) reported that stretching had little or possibly a or negative effect on 20- m sprint performance of track and field athletes. Conversely, others have reported that a mix of static and dynamic stretching can significantly improve 20 m sprint performance in soccer players from 3.71 ± 0.11 to 3.65 ± 0.65 s (Alikhajeh, Rahimi, Fazeli, & Fazeli, 2012), and rugby players improved 20 m time after stretching (3.24 ± 0.2 to 3.18 ± 0.18 s) (Fletcher & Jones, 2004) One thing to note is that studies reporting no significant improvement in sprint performance only examined the acute effects of stretching rather than training or chronic effects.

Overall, debate continues in the literature, not only about which stretching technique is the best to enhance performance but also how much time a stretch should be practised in order to improve sprint performance (De-Baranda & Ayala, 2010; Shrier, 2004; Weerapong, Hume, & Kolt, 2004). Weerapong et al. (2004) recommended a minimum of 30 s and a maximum of 60 s of static stretching was required in order to observe any changes in the muscle, therefore, it is possible that the time spent by participants in the Nelson et al. (2005) study was insufficient to see physiological change and therefore sprint performance benefit.

In other words, the time spent by players stretching the sport-specific muscles could be considered as a crucial factor to improve flexibility and to have any positive effect on sprint performance (Weerapong et al., 2004). Fletcher and Jones (2004) & Alikhajeh et al. (2012) used 20 repetitions of 20 s mixed stretching (static and dynamic) and showed significant improvement in sprint time. Shrier (2004) suggested that long-term practice of stretching exercises may improve force production, jump height, and speed. Gleim and Mchugh (1997) recommended that regular practice of stretching could increase the adaptability of muscle and joint pliability, and Knudson, Bennett, Corn, Leick, and Smith (2001) advised stretching after every physical activity performed may result in improved muscle performance and eventually improved speed (Medeiros, Cini, Sbruzzi, & Lima, 2016). Overall, the above studies indicate that a consensus is yet to be reached on the use of stretching programmes to improve performance.

To date, only a few researchers have explored the chronic effect of a stretching routine or flexibility intervention. Some researchers consider flexibility as a vital component of fitness which plays a significant role in rugby players' performance (Eaton & George, 2006; Fletcher & Jones, 2004). In contrast, several others remain sceptical about the role of flexibility in improving athletic performance (Bazett-Jones, Gibson, & Mcbride, 2008; Chan, Hong, & Robinson, 2001; Favero et al., 2009; Feland, Myrer, Schulthies, Fellingham, & Measom, 2001; Perrier et al., 2011).

There is a dearth of knowledge on the long term effect of a traditional Indian stretching routine on athletic performance. Yoga, a traditional Indian holistic exercise practice, is a combination of physical postures (Asana), breathing exercises (Pranayama), and meditation (Dhyana), which focuses on the physical and mental aspects of an individuals' movements (Barnes, Bloom, & Nahin, 2008; Brunelle et al., 2015; De-Michelis, 2005; Feuerstein, 2002; Pritha, 2009). This study employed yoga, focussed on various body positions to stretch muscles in conjunction with an emphasis on controlled breathing exercises.

For this study, a physical routine of yoga postures with breathing was explicitly designed for rugby players. The aim of the study was to assess whether a yoga (stretching) intervention practised by male rugby players alongside their usual rugby training had any effect on their subsequent flexibility and sprint performance.

4.4 Method

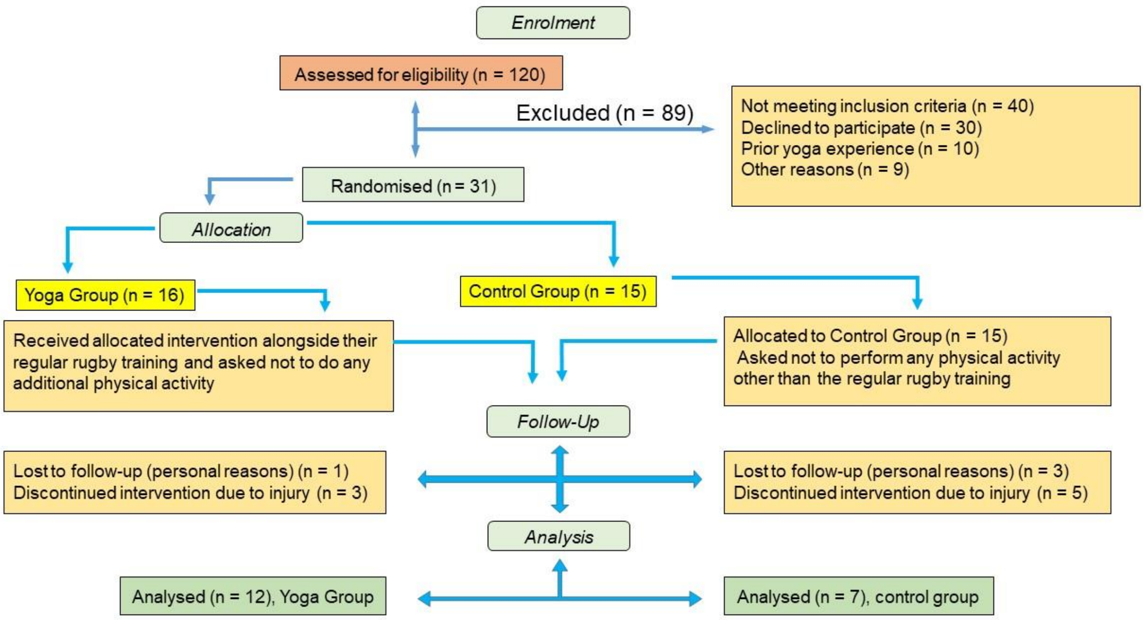
A yoga intervention was specifically designed for rugby players and delivered by a registered yoga instructor (registered exercise professional, New Zealand). Rugby is, by nature, a team game played outdoors with varying weather and field conditions, making it difficult to determine a single, game-based measure of physical performance. However, rugby players are required to complete a number of short sprints of 5-30 m, so sprint speed was used as the measure of rugby athletic performance (Darrall-Jones, Jones, & Till, 2015). All participants were in the same yoga class, and all sessions were completed in a yoga room.

During the 8 weeks of intervention, players spent the first 10 min performing sun-salutation sequence (a set of 12 dynamic stretching postures) an easy to follow routine aimed at producing a standard warm-up before each session. Players then performed stretching to the lower body with postures as follows; 17 sets of 30 s stretchs focussing on quadriceps, hamstring calves in five different postures; three postures with 13 sets of 20 s stretches focusing on hamstrings; 17 sets of 10 s stretches focussing on gluteal and lower back area in eight postures. The players then performed postures to stretch the upper body including;10 sets of 15 s stretches focussing on shoulders, upper-back, and abdominal area in six postures; 4 sets of 15 s stretching focussing on the middle back in four postures; and 4 sets of 20 s stretches focussing on hip abductor and hip adductors in two postures. The postures performed during the intervention are typically combination exercises using several joints and muscles. Total time spent on stretches amounted to 45 ± 2 min (mean ± SD) at each yoga session. Players spent approximately 25 ± 3 min performing dynamic stretching, which included 10 min of sun-salutation practice, and around 15 - 20 min in both dynamic and static stretching postures. Players were also required to complete 10 min of savasana/mindful relaxation/recovery at the end of every session.

4.5 Participants

In the current study, a strategic sampling method was employed to recruit the rugby players from a local rugby union football club. A spreadsheet was used to calculate the number of participants required in the study with the smallest worthwhile change in performance being 1.0% and the typical error or within-subject SD in similar tests of 0.7%. Using a type 1 error of 0.5% and a type 2 error of 25% the number of participants in a pre-post parallel-groups controlled trial was calculated to be 7 per group. Initially, thirty-one male rugby players (19.5 ± 0.9 years) volunteered for the study (Table 5). However, only nineteen players (yoga n = 12) (control n = 7) completed the study and 2 players could not complete due to injuries, 3 due to personal circumstances, 2 changed their club, and 1 relocated within New Zealand while, 3 relocated outside New Zealand “see Figure 2”.

Figure 2. Flow chart describing the selection and categorisation of subjects from the rugby clubs for the present analysis.



All players were novices to the practice of yoga. Players were matched for baseline 5 m split time by ranking their 5 m performance. From the ranked performance successive pairs of players were randomly divided either to the yoga group (practised yoga for 1 hour, two times per week for 8 weeks in addition to their normal 90 min two times a week rugby training, 80 min weekly game time, and 120 min of strength and conditioning time) or the control group (continued with their normal rugby training, game time, and strength and conditioning time without yoga). All players completed a medical questionnaire and reported no contradictions to maximal exercise. All players were free from any current or previous injuries that may have hindered their participation in the current study. All players were also informed about the possible risks of volunteering for this study and provided written informed consent prior to the study. Following the Declaration of Helsinki, this research was approved by the Lincoln University Human Ethics Committee (HEC approval number 2017-14).

Table 5. Physical characteristics and playing experience of the yoga and control groups in the male rugby union players.

Group	Yoga group (n=12)	Control group (n=7)
Age (years)	19.1 ± 0.9	19.6 ± 0.9
Height (cm)	181.3 ± 8.1	182.7 ± 4.1
Weight (kg)	88.9 ± 18.7	85.5 ± 9.4
BMI ($m.^{-2}$)	26.6 ± 5	26.6 ± 3.3
Rugby experience (years)	4.0 ± 1.3	3.5 ± 1.3

Data are mean ± SD.

4.6 Exclusion criteria

Any subject who had any current or previous injury or medical condition that does not allow them to perform yoga postures or the various fitness tests were excluded from the study.

4.7 Yoga intervention

Yoga classes were offered two times a week for 8 weeks, which started at the beginning of the rugby season. The average attendance rate for the yoga group was 75% (12 sessions), with some players attending all (15) sessions, whereas others only attended (9) sessions. Each yoga session consisted of a warm-up of 10 min with Surya-namaskar (dynamic stretching sequence of 12 postures) followed by 35 min of yoga postures (10 min standing, 10 min sitting, and 15 min of supine and prone postures and a mix of static and dynamic postures) and 10 min relaxation in the final resting position (lying in supine position without any stretching exercise), plus 5 min was allocated for transitions between postures. The sessions consisted of 32 yoga postures (including standing, sitting, forward bending, backward bending, spinal twist, core engagement and body inversion) targeting the major muscle groups of the body (e.g., gastrocnemius, hip flexors, hip extensors, abdominals, and trapezius). Basic breathing and relaxation techniques were taught in the first 2 weeks of the intervention after the initial session players practised these two techniques for the remaining six weeks. The yoga postures were modified to improve the range of motion, and promote the progression of difficulty and intensity with the support of yoga props (such as blocks, straps, or ropes), so movements were performed as accurately as possible without inducing pain beyond that experienced with stretching.

4.8 Testing protocol

After providing all background information and receiving signed informed consents for the study, two weeks were allocated for the collection of baseline measurements of participants. During this period sport-specific assessments were also performed.

4.8.1 Flexibility of the hamstrings

A baseline examination was carried out 1-2 weeks before the yoga intervention and again 1-2 weeks after the last yoga session. The hamstring flexibility of players was measured in a seated position (Yamamoto et al., 2009) in front of a Flex-Tester© box (Novel Products, Inc.; Rockton, IL, USA). Each player performed a warm-up which consisted of a slow jog for 5 min, followed by 10 min of dynamic and static stretching exercises (Hamlin, Olsen, Marshall, Lizamore, & Elliot, 2017). The hamstring flexibility test consisted of 3 sit-and-reach tests where players were instructed to keep their knees fully extended in front of them with the soles of their feet (without shoes) placed against the box. Players then placed one hand on the top of the other hand and pushed the measuring tab of the box in a slow and controlled movement as far forward as possible which was held for 2 s at maximum reach (Yamamoto et al., 2009). Players were not allowed to flex their knees during the test and players were required to have a 2 min rest between each attempt, with the best of 3 attempts used in the analysis.

4.8.2 Performance

After completing the hamstring flexibility test, sprint performance was measured using three 30 m sprints. The sprint was analysed in two acceleration phases (5 and 10 m) and maximal velocity (30 m) (Darrall-Jones et al., 2015). Each participant completed the sprint from a standing start position, placing their desired leading foot on a mark 30 cm behind the starting line, and ran through the electronic timing gates. Time (to the nearest 0.01 s) for each sprint was recorded using a set of electronic speed-timing lights placed at 5, 10 and 30 m (Smartspeed, Fusion Sport Ltd, Australia). There was a required 2 min recovery between each sprint, and the mean of the fastest sprint time of 3 attempts was used in the analysis. All players were asked not to perform any strenuous exercise in the 24 hours prior to testing. The testing and re-testing was completed at the same time of day on a large covered slip-free floor area under similar climatic conditions.

4.9 Statistical analyses

A total of 19 players were tested for pre- and post-intervention. Both groups were similar in age; the yoga group was 19.1 ± 0.9 while the control groups' age was 19.6 ± 0.9 years. Both groups were also similar in their height; yoga group 181.3 ± 8.1 cm and control group 182.7 ± 4.1 cm. However, the yoga group was heavier 88.9 ± 18.7 kg compared to the control group 85.5 ± 9.4 kg. The BMI of the yoga group 26.6 ± 5 and the control 26.6 ± 3.3 group were similar. The mean of the fastest sprint time and highest flexibility scores of individual players at pre- and post-testing were used in the group analyses. Interactions between group and differences between pre- and post-intervention scores were analysed using analysis of variance (ANOVA). Statistical analyses were performed using SPSS 24 for Windows (SPSS, Inc., Chicago, IL). Significance was set at an alpha level of $p \le 0.05$. Data given represents the mean ± SD unless stated otherwise.

4.10 Results

The yoga group showed a small decrease (-1.2% ± 21.4) in hamstring flexibility compared to the control group which demonstrated a significant decrease (-14.8% ± 23.7) (mean % change ± 95% CI, $p < 0.05$). Additionally, the yoga group showed a small but non-significant improvement of – 3.2% ± 10.4, and - 0.7% ± 9.0, in their sprint time when compared to the control group -0.4% ± 10.2, 0.0% ± 7.9, in 5 and 10 m respectively (Table 6).

Table 6. Hamstring flexibility and 5, 10, 30 m sprint time of the yoga and control group in the male rugby union players

	Control Group			Yoga Group			
	Pre (n = 7)	Post (n =7)	Control Group Pre-Post % Change (± 95% CL)	Pre (n = 12)	Post (n = 12)	Yoga Group Pre-Post % Change (± 95% CL)	Between Group Pre-Post % Change (± 95% CL)
Flexibility (cm)	32.3 ± 9.4	26.0 ± 12.9	-14.8% (23.7)	31.1 ± 11.1	30.9 ± 9.4	-1.2% (21.4)	17.3% (30.8) *
5 m Sprint (s)	1.01 ± 0.07	1.01 ± 0.15	-0.42% (10.21)	1.07 ± 0.05	1.04 ± 0.14	-3.2% (10.4)	-2.7% (10.4)
10 m Sprint (s)	1.78 ± 0.11	1.80 ± 0.23	0.37% (7.85)	1.82 ± 0.14	1.81 ± 0.20	-0.7% (9.0)	-1.1% (8.4)
30 m Sprint (s)	4.35 ± 0.27	4.57 ± 0.60	4.37% (7.13)	4.52 ± 0.31	4.54 ± 0.40	0.2% (5.4)	-4.1% (6.7)

Data are raw mean ± SD of each group with the difference within and between groups given as the percent mean difference ± 95% confidence interval. *Statically significantly ($p < 0.05$).

4.11 Discussion

This study found that rugby players who undertook 8 weeks of static and dynamic stretching during a weekly 1 hr yoga intervention, in addition to their normal rugby training sessions, had a minimal decrease in their hamstring flexibility compared to players who did the rugby training only. However, this flexibility training through the yoga intervention did little to improve their flexibility from baseline -1.2 ± 21.4% (pre- to post-change ± 95% CL) after intervention. However, the 5 m and 10 m short sprint performance of the yoga group was improved -3.2 ± 10.4% and 10 m -0.7 ± 9.0% (pre- to post-change ± 95% CL) compared to the control group -0.42 ± 10.21% and 0.37 ± 7.85%.

Stretching has become a central part of most athletes' exercise training programmes and is generally employed to maintain muscle length, muscle flexibility and joint range of motion (Medeiros et al., 2016). However, the effect of chronic stretching on improving muscular performance is controversial with research showing little (Hunter & Marshall, 2002) to no beneficial effect (Bazett-Jones et al., 2008). In agreement with these studies, no significant beneficial effect or improvement were found in the flexibility of the experimental group (receiving yoga intervention) compared to controls.

The controversial issue of stretching to improve performance is based on several postulated mechanisms. Dynamic movement requires the contraction and elongation of the muscle-tendon unit (and thereby, movement of the limb around the joint). This stretching and shortening (stretch-shortening cycle) relies on the elastic proprieties of the tendon to enable the release of potential energy. Hence the elastic property of the muscle-tendon unit is crucial and is influenced by the stiffness of both tissues. It is believed that greater compliance (i.e. less stiffness) in these tissues improves energy storage, thereby enhancing muscle performance (Wilson, Elliott, & Wood, 1992). Given that the yoga (stretching) group improved flexibility, compared to the control group, which may have increased muscle compliance, this did not seem to change muscle performance during sprinting in the rugby players measured in this study. This suggests that either tissue compliance did not change (and the relative increase in flexibility is due to other mechanisms), or that there is little effect of increased compliance on sprint performance. On the other hand, while the yoga group showed a significant change in flexibility compared to the control group (an average of 17.3%), in reality, the significant change between groups is probably due to the fact that the flexibility in the control group decreased (-14.8%) while the flexibility in the yoga group changed little from baseline (-1.2%). Therefore, if the flexibility did not change in the yoga group, one would not expect to find greater muscular compliance and thus little change in performance.

Since there was no substantial increase in the flexibility of the yoga group (i.e. it maintained rather than improved flexibility), perhaps the yoga sessions were not long or intense enough to cause muscle adaptation and therefore impact performance.

Previous research Petric, Vauhnik, and Jakovljevic (2014) has found that yoga practised for 75 min 2 times per week for 20 weeks (average of 150 min per week) improved sit and reach scores by approximately 13 cm in the first 10 weeks and 17 cm at the end of training in healthy adults. The players in the current study completed approximately 90 min per week for 8 weeks, which may indicate a larger stretching dose is required to achieve significant flexibility changes. In addition, not all players in the current study attended every yoga session, with an attendance rate of only 60% compared to 78% in the Petric et al. (2014) study. Overall, this would suggest the players in the current study received substantially less muscle stretching time, which resulted in a lower stretching dose and therefore less muscle adaptation. Any future studies in this area should prepare a guideline for players, which will allow them to complete at least 150 min of yoga per week, which could be either 30 min of stretching 5 days per week or incorporating a longer stretching routine time (75 min/session) with less frequency (two times per week) on muscle stretching for a minimum of 12 and up to 20 weeks.

4.12 Conclusions

In conclusion, the stretching employed in the current study by the yoga group was enough to buffer any loss in sprint performance associated with flexibility. The results of the current study did not result in any significant improvement in sprint performance, therefore this will remain speculative and would require further research before this theory can be confirmed.

Chapter 5

Association between hamstring flexibility and 20 m sprint speed after 12 weeks of yoga in female rugby players.

5.1 Preface to Study 3:

The results from study 2 (chapter 4), indicated that 8 weeks of yoga effectively maintains the sprint performance and did little to improve the flexibility of male rugby players. The lack of positive change in the yoga group was concerning (as there was no change from the baseline results in the flexibility of the yoga group), which may have been due to the shorter yoga intervention (8 weeks, rather than 12 weeks), or poor attendance rate not allowing sufficient time for adaptations to occur. In addition, the lack of sensitivity in the sit and reach measurement for lower body flexibility may have also affected the results from study 2. Currently, there is a lack of information on such training in female athletes. Finally, the amount of time spent at each yoga session in the two previous studies was held at 60 min, which is a considerable amount of time given the players are required to complete other aspects of training including strength and conditioning, skill-related training and game instruction as well. Therefore, in this study, a shorter session time (30 rather than 60 min), in females, using more sophisticated lower body flexibility measurements along with traditional sprint speed measurements were chosen to investigate the effect of a 12 week yoga intervention.

Authorship:

Tilak Raj, Michael J. Hamlin, Catherine Elliot

Faculty of Environment Society and Design, Department of Tourism, Sport & Society, Lincoln University, New Zealand.

5.2 Abstract

The purpose of this study was to evaluate a structured yoga intervention on hamstring flexibility and 20 m sprint performance in female rugby union players. Players were randomly assigned to an experimental group (n=5) that practised yoga for 30 min two times a week for 12 weeks in addition to their normal rugby training (180 min weekly), or a control group (n=5) with regular rugby training but no yoga intervention. Data was collected during pre-season and mid-season on hamstring flexibility (popliteal angle and straight leg raise test), and sprint performance (measured at 5, 10, 15 and 20 m). The Statistical Analysis System (Version 9.3, SAS Institute, Cary NC) was used for the analysis of performance measures (pre versus post) using unpaired t-tests with an alpha level of $p \leq 0.05$ between the yoga and control groups. Data was checked for normality and Pearson correlation was also performed to investigate the association between variables. Players who completed the 12 week yoga intervention significantly improved their straight leg raise (SLR) test 29.1 ± 15.3-degrees (mean % change ± 95% CI, $p < 0.05$). While the control group did not change significantly 2.9 ± 15.3 ($p > 0.05$). Players who completed the 12 week yoga intervention also improved their 5 m sprint time -10.4 ± 10.2 s (mean % change ± 95% CI, $p < 0.05$) compared to the control group 9.9 ± 6.1 s (p > 0.05) which became slower. There was also a moderate negative correlation between straight leg raise and 5 m sprint performance time (r = -0.43) indicating that as the flexibility of the leg increases there is a decrease in the sprint time, however, it was statistically not significant (p = 0.21). Results indicate that a 12 week yoga intervention was beneficial at improving the hamstring flexibility of rugby players compared to a control group. Yoga helped rugby players to improve their hamstring flexibility when practised alongside normal rugby training but did little to improve sprint performance during the season.

5.3 Introduction

Rugby is one of the most popular and commonly played sports in England, Ireland, Australia, and New Zealand (World Rugby, 2017). Like many team sport athletes, rugby union players spend considerable time walking and jogging during a game but also spend about 10% of their time in higher intensity running and sprinting (Busbridge et al., 2020; Duthie et al., 2006). Efficient sprinting is not only associated with power and strength but also with the range of motion in the joints and muscle flexibility (Arampatzis, Bruggemann, & Metzler, 1999).

Rugby is a highly professionalised game, and there has been a shift in the physiological and technical demands required by rugby players in the last decade; players now need to be faster and stronger to compete at a high-performance level (Darrall-Jones et al., 2015; Hill et al., 2018; Smart, Hopkins, & Gill, 2013). This is also the case for female players with a recent study reporting that players cover a similar overall distance in a game as male players (somewhere around 5 km) of which about 10% or 500 m to 700 m is high-intensity running and sprinting (Busbridge et al., 2020). Sprinting is a high-intensity activity, requiring a combination of flexibility, anaerobic endurance, and muscular contractions to produce explosive power (Lockie, Jalilvand, Callaghan, Jeffriess, & Murphy, 2015; Silder, Besier, & Delp, 2015; Živković & Lazarević, 2011). Female rugby players spend between 6 to 14 percent of their game time completing high-intensity activity, while 4 to 25 percent of their time is spent in high intensity sprinting depending on the playing position (Busbridge et al., 2020; Cahill, Lamb, Worsfold, Headey, & Murray, 2013; Duthie et al., 2006). Therefore, it is essential for players to have adequate flexibility of the body parts involved in the locomotor system to maintain performance and prevent injury (Ekstrand, Gillquist, & Liljedahl, 1983; Jonhagen, Nemeth, & Eriksson, 1994; Shellock & Prentice, 1985). Superior elasticity of the leg muscle-tendon unit can provide additional power to a player's running performance up to 6.5 $m \cdot s^{-1}$ (Chelly & Denis, 2001).

Stretching is widely accepted for its effectiveness in increasing muscle length 6. 8 ± 1.1% and joint range of motion (increased from 94 to 125°) (Tsolakis & Bogdanis, 2012; Vasileiou, Michailidis, Gourtsoulis, Kyranoudis, & Zakas, 2013). Moreover, adequate flexibility may provide an ideal platform on which skills required to develop speed and strength can be gained (Živković & Lazarević, 2011). Similarly, reduced flexibility is associated with decreased range of motion, increased risk of muscular injury, and adverse effects on performance (Arampatzis et al., 1999; Czaprowski et al., 2013; Witvrouw, Danneels, Asselman, D'have, & Cambier, 2003). Witvrouw et al. (2003) measured the pre-season flexibility of male professional soccer players and found that muscular flexibility plays a significant role in determining a future injury. For example, Witvrouw et al. (2003) revealed that quadriceps and hamstring muscle stiffness was responsible for 80% of the injuries to the players.

Static or dynamic stretching routines are commonly used by coaches and trainers to improve flexibility (Febbraio, Carey, Snow, Stathis, & Hargreaves, 1996; Gleim & Mchugh, 1997), and flexibility has been a vital part of warming-up and cooling-down sessions for more than five decades (Fletcher & Jones, 2004; Racinais, Cocking, & Periard, 2017). However, flexibility programmes used on explosive sports players have reported a mix of results (Bradley et al., 2007; Jaramillo et al., 2013; Lima et al., 2019; Paradisis et al., 2014; Sayers et al., 2008; Shrier, 2004; Skaggs et al., 2015; Živković & Lazarević, 2011). As a consequence, whether to perform static or dynamic stretching to improve explosive sports performance remains debatable (Dintiman, 2013; Gleim & Mchugh, 1997; Paradisis et al., 2014; Sayers et al., 2008; Shrier, 2004).

Many researchers support the idea of including stretching as part of athletic training (Gleim & Mchugh, 1997; Shellock & Prentice, 1985; Weerapong et al., 2004), but the mechanisms underpinning the adaptation of the muscle-tendon unit with such training are uncertain (Blazevich et al., 2014), along with potential performance gains from such stretch training interventions (Chalmers, 2004; Sahrmann, Azevedo, & Dillen, 2017). Guissard and Duchateau (2004) observed that after 6 weeks of static stretching for 10 min/day, 5 days per week, there was a significant decrease in passive stiffness (torque) of the muscle along with an increased range of motion in the joint. These researchers hypothesized that the increased compliance of the muscle-tendon unit resulted from a change in the viscoelastic properties or a reduction in reflex stiffness. More explicit work by Guissard and Duchateau (2006) suggests the increased passive stiffness after stretching may be associated with either reduced motor neuron excitability or reduced firing of type Ia afferents to the motor neuron pool. On the other hand, evidence suggests that stretch training may reduce the tonic firing of the muscle spindle itself, probably due to a reduction in the sensitivity of the receptor or increased compliance of the passive elastic components of the muscle-tendon unit (Guissard & Duchateau, 2004, 2006).

While it is commonly accepted that stretching improves the range of motion in the joint and reduces the tension in the muscle-tendon unit (Amin & Goodman, 2014; Wilson et al., 1992), whether stretching improves performance is controversial (Bazett-Jones et al., 2008). A number of studies have found that stretching can improve muscle strength (Kokkonen, Nelson, Eldredge, & Winchester, 2007; Worrell, Smith, & Winegardner, 1994) and thereby muscular power (Kokkonen et al., 2007), probably by increasing hypertrophy of the muscle (Coutinho et al., 2004; Day, Moreland, Floyd, & Huard, 1997; Stauber, Miller, Grimmett, & Knack, 1994). Alternatively, stretching can result in increased muscle length (Coutinho et al., 2004), which may result in increased contractile velocity and force at a given velocity (Lieber, 2002). Increasing the ability to produce force and power of the muscle from chronic stretching may therefore have a positive effect on athletic performances like sprinting. However, the majority of the previous studies have been conducted on male rugby players, with very few on female rugby players.

Yoga is an ancient Indian practice that involves whole-body movements to enhance joint range of motion (ROM). This type of yoga includes various static and dynamic stretching positions performed in a multi-planar manner for various durations ranging from 10-30 s. Little research has been undertaken on assessing the contribution of yoga towards enhancing flexibility and sprint performance. For this study, yoga was the vehicle for a chronic stretching programme. The aim of this study was to examine the effects of a regular yoga routine on the flexibility and sprinting ability of female rugby players.

5.4 Method

To measure the effectiveness of a yoga intervention on the flexibility of the lower limbs along with the sprinting ability of the players, in the current study female players were matched based on their 5 m performance data collected at baseline and then randomly assigned to either yoga or the control group. Players were tested 1-2 days before (pre) and 1-2 days after (post) a 12 week yoga intervention specifically designed for rugby players. A spreadsheet was used to calculate the number of participants required in the study with the smallest worthwhile change in performance being 1.0% and the typical error or within-subject SD in similar tests of 0.7%. Using a type 1 error of 0.5% and a type 2 error of 25% the number of participants in a pre-post parallel-groups controlled trial was calculated to be 7 per group.

5.4.1 Subjects

A total of 14 senior-level female rugby players aged 20.5 ± 1.3 (mean ± SD) volunteered to participate in the study. None of the players had practised yoga regularly. All female rugby players had been playing rugby for three years or more (Table 7) and were from a local rugby football club where they attended 180-min rugby-specific training, one game (80 min) per week and 120 min of strength and conditioning weekly. All the participants in the study were free from any current or previous injury that would affect their full participation in the current study. Lincoln University Human Ethics Committee approval was obtained for this study (HEC approval number 2017-14). All players were informed about the research, and they provided written consent. Four females could not complete the entire study due to their personal/family commitments, so their data was excluded from the assessment. In total, data on ten players were evaluated. Players in this study were divided into two groups; an experimental group (EG) which practised yoga for 30 min two times a week in conjunction with their regular rugby training (n=5), and a control group (CG) which continued their regular rugby training but without the yoga intervention (n=5).

During flexibility testing to reduce the influence of stretching on flexibility, participants were instructed to refrain from warming up before testing was performed. Before testing, subjects were asked to be barefoot and wear comfortable clothing, and they were asked to take a supine position in a room with the temperature controlled at 19 degrees. The tests were carried out twice with a 1 min rest given between the measurements according to the procedures outlined by Czaprowski et al. (2013). To assess the hamstring flexibility, the straight-leg-raise (SLR) test and popliteal angle (PA) test (explained below) were applied on the right and left side of the body in a randomised manner, and results of both sides were used for analyses.

5.4.2 Straight-leg-raise test

The SLR test followed the procedure established by Czaprowski et al. (2013) which involved measuring the players in the supine position on the bed with lower limbs extended, feet relaxed, with an engaged trunk and pelvic area. The researcher randomly selected the side (right or left) to test first. As instructed, players raised either their right or left leg as high as possible until the point where discomfort was felt in the hamstring. The researcher then assessed the range of hip flexion using a goniometer (PM0064, Prestige, New Zealand) and repeated the test three times on each side of the body, while one min rest was provided between tests and the best score (joint angle in degrees) from both sides was used for analysis.

5.4.3 Popliteal angle test

To test the PA, the researcher followed the instructions described by Czaprowski et al. (2013). The PA was measured when the players were in the supine position on the bed with the hip flexed at 90^{O}. The player remained in this position holding the posterior aspect of the thigh. Each player was instructed to hold the thigh of the measured leg and straighten the knee until the point where discomfort was felt in the hamstring. The researcher used a goniometer (PM0064, Prestige, New Zealand) to ensure 90^{O} of hip flexion was maintained during the measurement of the opposite side hamstring. The player was asked to straighten the lower leg, and another researcher used the goniometer (PM0064, Prestige, New Zealand) to measure the popliteal angle. The test was repeated three times on each side of the body, with 1 min rest provided between tests. The best score (joint angle in degrees) from both sides was used for analysis.

5.4.4 Sprinting

To analyse the 20 m sprint I used a protocol described by Darrall-Jones et al. (2015). The 20 m sprint was analysed in three phases, acceleration was measured over the first 5 m and 10 m, and maximal velocity was measured over the final 10 m. Each player was required to complete two 20 m sprints from a standing start position with 2 min of recovery time between each sprint. The player placed her lead foot behind the 30 cm mark starting line and ran through the electronic timing gates placed at 5, 10 and 20 m (Fusion Sport, Coopers Plains, Australia).

5.4.5 Yoga intervention

A 30 min yoga intervention class was given twice a week for 12 week (24 sessions) by a registered yoga instructor. All players attended at least 75% (18) of the yoga sessions, consisting of different postures designed to address all the major muscle groups, including hamstring, quadriceps, and abductors. Each player actively performed 21 yoga postures in total which involved all possible planes of the body, 11 of which were static stretching postures and 10 were dynamic stretching postures. A sun-salutation (dynamic stretching sequence of 12 postures) was used for warm-up and savasana was used as a final resting position (no stretching included). To ensure the uniformity of the yoga sessions, the yoga teacher performed the postures in front of the players prior to the players trying the posture on their own, each posture was held for approximately 10 to 30 s, as controlled by the researcher. A minimum of 5 s were also allocated for changing the postures, also a minimum of 30 s rest was given between the transition of the postures from a standing position, to a sitting position, to supine, and a prone position.

Players spent the first 4 min performing sun-salutation sequence (a set of 12 dynamic stretching postures used as a warm-up) an easy to follow practice to keep the practice standard throughout the study. Players then performed 8 sets of 15 s stretches focussing on quadriceps, hamstring, calves in six different postures, 5 sets of 20 s stretches focusing on gluteal and lower back area in six postures, 9 sets of 10 s stretching focussing on shoulders, upper-back, and abdominal in five postures, two sets of 10 s stretching focussing on the middle back in one posture, and two sets of 20 s stretching focussing on hip abductor and hip adductors in two postures. Typically, a combination of joints and muscles are used during each posture. Players were also required to do a 5 min of savasana/mindful relaxation/recovery at the end of the session.

Seven of the 21 postures were focused on stretching the lower body (e.g. adho-mukha svanasana and prasarita paddottansana), these were performed as both static and dynamic and either in a standing or in a supine position. Three of the 21 postures were stretching the shoulder region (e.g. bandha hastasana) of the body which was also performed either in a standing or sitting position. Five of the 21 postures were variations of the sit and reach posture for stretching the anterior and posterior plane of the body.

Four of the 21 postures focussed on supine postures (e.g. supta padangustasana 1 and setu-bandh asana). Two of the 21 postures were to twist and provide length in the spinal region. The yoga intervention was progressively challenging, and all players were in the same yoga class which was completed in a large open fitness studio room. Players were verbally encouraged to perform the yoga posture to the best of their ability. The yoga intervention protocol is accessible by contacting the authors.

5.5 Analysis of data

Initially, the data was collected from 14 players, however, only 10 players were able to complete the study with the data of 4 players excluded from the analysis. The Statistical Analysis System (Version 9.3, SAS Institute, Cary NC) was used to calculate means and standard deviations for the various anatomical and performance measures from each of the two tests (pre versus post). Residuals from the SAS output were initially checked for normality. Differences in variables between the yoga and control groups were determined using repeated measures analysis which enabled the comparison of baseline to post-test in both groups and also the baseline to post-test difference between groups. Worthwhile differences between groups was calculated using Cohen's value of 0.2 of the between-subject standard deviation (Cohen, 1988). Proc Cor (SAS Institute, Cary NC) was used to calculate Pearson correlations between all variables to provide an indication of the overall association between the testing protocols, with an alpha level of $p \leq 0.05$ (Table 9).

5.6 Results

Total time spent on stretches amounted to 21 ± 2 min (mean ± SD) at each yoga session. Players spent approximately 13 min performing dynamic stretching, which included 4 min of sun-salutation practice, and around 8-9 min in both dynamic and static stretching postures. Only the five female players in the yoga group were able to complete the study, two of the five players attended all 24 sessions, one player missed six sessions (none of them were consecutive sessions) due to personal circumstances (study, family, and health). Two players missed two consecutive sessions due to injury. There were no statistically significant differences in any of the measures between the groups at baseline (Table 7).

Table 7. Physical characteristics and playing experience of the yoga and control groups in female rugby union players.

Group	Experimental (n=5)	Control (n=5)
Age (Years)	20 ± 1	20 ± 3
Height (cm)	166.9 ± 4.5	172.4 ± 5.9
Weight (kg)	70.4 ± 7.7	72.3 ± 6.7
Rugby experience (Years)	4.4 ± 0.8	4.2 ± 0.74

Data are mean ± SD.

There was no significant change in the PA as a result of the yoga intervention, but the five players who completed the 12 week yoga intervention significantly improved their SLR test 29.1 ± 15.3-degrees (mean % change ± 95% CI, $p < 0.05$) (Table 8). Whereas the control group did not change significantly 2.9 ± 15.3 ($p > 0.05$). Players who completed the 12 week yoga intervention showed small to moderate change in flexibility, improved their 5 m sprint time -10.4 ± 10.2 compared to the control group 9.9 ± 6.1, and had a significant and worthwhile meaningful change of -18.4% (10.6) in pre- post- intervention (Table 8). Although other measures of flexibility did not reach statistical significance, the change observed was more than the smallest worthwhile change (Table 8).

Table 8. Change in the flexibility and sprint time in female rugby players before and after a 12 week yoga intervention.

	Control Group			Experimental Group			
	Pre (n = 5)	Post (n =5)	Pre-Post Change (± 95% CL)	Pre (n = 5)	Post (n = 5)	Pre-Post Change (± 95% CL)	Between Group Pre-Post % Change (± 95% CL)
SLR Right Leg $^{(0)}$	75.6±7.7	81.80 ± 7.2	8.0% (13.7)	66.6±11.7	85.8±10.3	26.1% (9.6)	19.8 % (21.3)$^{\#}$
SLR Left Leg $^{(0)}$	78.4±10.4	80.4 ± 8.5	2.9% (18.6)	64.8±11.9	86.0 ± 4.3	29.1% (15.3) *	30.0 % (33.4)$^{*\#}$
PA Right Leg $^{(0)}$	44.0±5.1	42.0 ± 4.5	-6.5% (35.0)	39.6±16.7	55.8 ± 3.4	42.1% (57.6)	62.5 % (131.1)$^{\#}$
PA Left Leg $^{(0)}$	43.0±15.5	49.8 ± 3.1	18.6% (30.1)	35.4±14.4	53.0± 2.8	47.3% (52.9)	33.2 % (95.6)$^{\#}$
5 m ST (s)	1.06±0.08	1.31±0.03	9.9% (6.1)	1.28±0.15	1.11±0.10	-10.4% (10.2) *	-18.4 % (10.6)$^{*\#}$
10 m ST (s)	2.03±0.08	2.14 ± 0.09	5.1% (4.6)	2.09±0.15	1.90±0.10	-3.5% (2.3)	-8.3 % (5.4)
15 m ST (s)	2.83±0.71	2.90 ± 0.07	3.4% (5.3)	2.89±0.13	2.76±0.03	-5.8% (4.1)	-8.8 % (6.5)$^{\#}$
20 m ST (s)	3.62±0.03	3.70±0.28	1.3% (6.7)	3.49±0.22	3.3±0.24	-1.3% (1.6)	-2.6 % (8.3)

Data are mean ± SD of each group with the difference between groups given as the mean ± 95% confidence interval. D: Angle measured in degree; s: time measured in seconds; SLR, Straight Leg Raise Test, PA, Popliteal Angle Test; * Statically significantly ($p < 0.05$), # worthwhile change observed (Cohen, 1988).

A correlation analysis were performed to observe the relationship between flexibility and sprint performance of female rugby players. A moderate negative correlation between straight leg raise in the left leg and 5, 10, and 15 m sprint performance time was observed in the yoga participants (r = -0.43, -0.21, -0.33 respectively), however, variables did not reach the statistical significance (Table 9).

Table 9. The correlation between the various flexibility variables and sprint performance in the yoga group.

	SLRR	SLRL	PATR	PATL	sprint5b	sprint10b	sprint15b	sprint20b
SLRR	1.00000							
	10							
SLRL	**0.77827**							
	0.0080							
	10							
PATR	0.74255	0.67080						
	0.0139	0.0337						
	10	10						
PATL	0.68319	0.50650	0.84392					
	0.0294	0.1352	0.0021					
	10	10	10					
sprint5b	-0.12652	**-0.42730**	-0.18906	-0.09120				
	0.7276	**0.2181**	0.6009	0.8022				
	10	10	10	10				
sprint10b	-0.12897	**-0.20172**	-0.25716	-0.20132	0.85323			
	0.7225	**0.5763**	0.4732	0.5770	0.0017			
	10	10	10	10	10			
sprint15b	-0.05792	**-0.32482**	-0.30285	-0.17812	0.90579	0.79495		
	0.8737	**0.3598**	0.3950	0.6225	0.0003	0.0060		
	10	10	10	10	10	10		
sprint20b	0.20017	0.18385	0.04250	0.23408	0.38764	0.35054	0.63565	1.00000
	0.5793	0.6112	0.9072	0.5151	0.2684	0.3207	0.0482	
	10	10	10	10	10	10	10	10

D: Angle measured in degree, s: time measured in seconds, SLR: Straight Leg Raise Test, PA: Popliteal Angle Test, m: distance is measured in meters. Data are Pearson correlation along with the p value ($p < 0.05$).

5.7 Discussion

The present study was designed to assess the effects of a yoga (stretching) intervention on the sprint speed and lower extremity flexibility of female rugby players when practised alongside regular in-season rugby training. The primary findings of the study were a significantly faster sprint time. The sprint time was 10% faster in the experimental group but 10% slower in the control group in the 5 m acceleration phase of the 20 m sprint. The experimental group also improved SLR hamstring flexibility of both legs (but only reaching statistical significance in the left leg) in the experimental group. A statistically significant and worthwhile change was recorded in the hamstring flexibility and 5 m sprint time of the yoga group.

While researchers have investigated the effectiveness of stretching routines mostly on males, including rugby players (Caplan, Rogers, Parr, & Hayes, 2009; Fletcher & Jones, 2004), sprinters (Jonhagen et al., 1994), soccer players (Sayers et al., 2008), and young adults (Bradley et al., 2007), this is the first study to examine a yoga (stretching) programme for female rugby players. Yoga is known to increase the joint range of motion (Amin & Goodman, 2014) and decrease recovery time (Brunelle et al., 2015), therefore it was hypothesised that including yoga alongside regular training might improve flexibility and sprint performance of the players in this study.

There is a considerable amount of literature indicating that static and dynamic stretching (as used in this study during the yoga session) are effective at improving flexibility in both acute and chronic settings (Caplan et al., 2009; Laroche & Connolly, 2006; Worrell et al., 1994). However, there is a paucity of information on the effectiveness of a yoga intervention or a mixed-method (static and dynamic) stretching routine on improving sprint performance and flexibility. It is speculated that flexibility is increased when the muscle-tendon unit decreases its stiffness (Wilson et al., 1992). This is supported by previous work from Laroche and Connolly (2006) who reported that flexibility is increased from enhanced stretching tolerance of the muscle, implying an adaptation and change in the elastic properties of skeletal muscle in response to the stretching programme. Researchers have also suggested a temporal effect prior to flexibility change, which can take between 3-8 weeks

(Laroche & Connolly, 2006; Turki-Belkhiria et al., 2014) or 8-12 weeks (Raj, Hamlin, & Elliot, 2017) depending on the intensity of stretching. Since neither stretch tolerance nor muscle-tendon unit stiffness was measured directly in the current study, the mechanism underlying the gains in the flexibility of the players in this study are undetermined, thus other possible mechanisms were also explored to determine what was observed in the current study

Previous research indicates that the benefits from a regular stretching programme are improved flexibility and increased strength (Kokkonen et al., 2007). Although flexibility gains are correlated with reduced sprint time, this correlation may not show a direct cause and effect. Kokkonen et al. (2007) reported that recreationally active male and female participants in a stretching group increased flexibility and decreased sprint time, which were related to the change in the muscular strength. Likewise, yoga postures included in the intervention in this study may have increased muscle length which may have led to increased contractile velocity and force generation. Future research could include such measures to help understand the mechanisms involved.

Stretching exercises have been reported to induce muscle hypertrophy. Worrell et al. (1994) reported that 15 days of regular static stretching increases the maximal voluntary isokinetic torque, eccentric torque, and concentric torque of hamstring muscles. Yang, Alnaqeeb, Simpson, and Goldspink (1997) showed that a continually applied stretch for 6 days can result in an increase in the number of sarcomeres in series by about 20% in rabbits. Tsujimura, Kinoshita, and Abe (2006) showed that stretching the tibialis anterior muscles of young and adult rabbits at a rate of 0.5 mm 2 times a day for 20 days resulted in muscle growth of 7.1% (adult) and 4.8% (young). Similar results have been reported in rats (13% increase in soleus muscle mass and 30% increase of fibre area) (Stauber et al., 1994) when the muscle was stretched 3 times/week for 4 weeks. An increase in muscle hypertrophy in the leg muscles of the players in the yoga group in this study may have increased the strength and therefore power of these players resulting in the improved 5 m sprint time. However, this is speculative until we can substantiate this theory with muscle strength and power data in subsequent studies.

Another unique aspect of the intervention that may have played a role in the sprint improvement observed in the experimental group could be the inclusion of dynamic stretching. Previous work suggests that dynamic stretching leads to enhanced motor unit excitability and improved kinaesthetic sense leading to improved proprioception and pre-activation (Mann & Jones, 1999). Furthermore, dynamic stretching may help in re-using the elastic energy during exercise that involves a stretch-shortening cycle (e.g. sprinting) (Wilson et al., 1992). This study found a significant improvement in the 5 m explosive sprint in the experimental group. It is important to note that the change was only correlated with the straight-leg-raise test of the left leg and the 5 m acceleration phase of the 20 m sprint. While we found small and worthwhile changes in other variables (SLR Right Leg, SLR Left Leg, PA Right Leg, PA Left Leg, and 15 m split time) these changes did not reach statistical significance. Therefore, more research on a larger population would be required to establish whether yoga or dynamic stretching consistently improves sprinting performance in this way.

5.8 Conclusion

A 12 week stretching programme (yoga programme in this study that involved both static and dynamic stretching) significantly improved the explosive 5 m sprint (e.g. time over the first 5 m) in female rugby players compared to controls. The stretching programme also improved the flexibility of the hamstring muscles in the leg. It seems that a yoga programme that involves 30 min twice a week for 12 weeks can positively affect hamstring flexibility as well as 5 m sprinting performance in female team sport players. The results suggest that a well-planned and controlled yoga programme incorporating static and dynamic stretches improves hamstring flexibility and explosive speed in young female rugby players.

5.9 Limitation

This study has a number of limitations. Firstly, the results of the current study do not allow us to suggest what type of stretching best suits rugby players since both dynamic and static stretching was used in the intervention and we are unable to separate out the individual effects. Secondly, we did not have a 3rd group to observe any placebo effect. Finally, our power calculation indicated we required 7 subjects per group, we only gathered data on 5 subjects per group, and therefore the study may be underpowered.

Chapter 6: The effect of yoga on cardiovascular risk factors and health parameters in a sedentary population.

6.1 Preface to Study 4

The investigations conducted in previous chapters of the thesis concluded a mix of results related to improving flexibility and sports performance of rugby players. The initial conceptualisation for the fourth study was to investigate the cardiovascular health benefits of yoga in athletes. However, over the past 2 decades, there is a considerable amount of literature available suggesting that athletes, in general, show a relatively low prevalence of the cardiovascular disease. Furthermore, exercise or training influences the parasympathetic tone leading to reduced heart rate and provides various health benefits.

On the other hand, cardiovascular disease is progressive in nature and to protect or gain benefits from physical activity, individuals don't need to be a high performance athlete. Researchers have estimated that there is a 30% to 40% reduction in cardiovascular health incidents just by meeting the Ministry of Health's physical activity guidelines (30 min or more of daily physical activity). Therefore, physical activity or exercise is considered to be extremely effective and safe at improving cardiovascular health.

In two of the three studies of this thesis, yoga was found to either help to maintain or improve flexibility of rugby players. However, yoga is not very well understood with regard to improved cardiovascular health. A recent study by Yamato et al. (2021) found that stretching exercise may induce changes in arterial stiffness (a strong predictor of cardiovascular disease). Therefore, in this last study, the association between regular yoga practice and cardiovascular health was investigated, along with how cardiovascular health may change with yoga practice. In addition, some of the postulated mechanisms involved will also be investigated. A cross-sectional study on yogis compared to healthy adults was prepared to investigate the relationships between physical activity such as yoga, and cardiovascular health.

Authorship:

Tilak Raj, Michael J. Hamlin, Catherine Elliot

Faculty of Environment Society and Design, Department of Tourism, Sport & Society, Lincoln University, New Zealand.

6.2 Abstract

A sedentary lifestyle is one of the major risk factors for cardiovascular disease. Yoga is a popular form of physical activity in New Zealand and an alternative wellbeing and exercise system which can help adults and older people to increase their weekly physical activity. The purpose of the present study was to examine the cardiovascular health markers in long-term yoga practitioners (yogis) and healthy individuals. The present study was a cross-sectional study which included 383 healthy male and female adults across all age groups (18 – 80 years), divided into two groups, yoga (n = 201) and control (n = 182). The Statistical Analysis System (Version 9.3, SAS Institute, Cary NC) was used for the data analysis. Carotid-femoral pulse wave velocity was used as the dependent variable and age, sex, flexibility, resting heart rate, body fat, skeletal muscle mass, body weight, smoking behaviour, meat consumption, salt intake, alcohol consumption, stress levels, body mass index and physical activity in metabolic equivalent (METmin) as independent variables. The yoga group had significantly lower carotid-femoral pulse wave velocity (0.13 ± 0.28, $m.s^{-1}$, $p < 0.05$) and systolic blood pressure (-2.04 ± 2.64, mmHg, $p < 0.05$), greater hamstring flexibility (12.7 ± 1.9 cm, mean ± 95% CI, $p < 0.01$), and higher total physical activity level ($METmin\text{-}week^{-1}$) (1035.1 ± 671.3, $p < 0.01$) compared to the control group. The control group had a higher blood glucose level compared to the yoga group (1.3 ± 2.9 mg/dl), but the yoga group had higher total cholesterol (15.0 ± 8.3 mg/dl). The control group was significantly taller (2.7 ± 1.7 cm, mean ± 95% CI, $p = 0.002$), heavier (8.2 ± 4.1 kg, $p < 0.01$), had more muscle mass (2.9 ± 1.5 kg, $p < 0.05$), higher BMI (2.0 ± 0.7, $p < 0.05$), waist-hip-ratio (0.05 ± 0.02 cm, p

< 0.01), and body fat (2.9 ± 3.1 kg) than the yoga group. Regression analysis of all participants indicated that age, sex, resting heart rate, flexibility and total physical activity were associated with lower carotid-femoral pulse wave velocity (r = 0.71). The findings from the current study suggest that regular yoga is associated with a number of health-related advantages compared to those who do not practise yoga. The findings also suggest that skeletal muscular stretching performed through yoga postures is associated with reduced pulse wave velocity, primarily in older participants.

Keywords: Physical activity, stretching, arterial stiffness, blood pressure, pulse wave velocity, heart disease, blood flow

6.3 Introduction

Cardiovascular disease is the leading cause of mortality globally, and New Zealand is no exception (Mendis, Puska, Norrving, & Organization, 2011) with the disease killing more than 10 thousand people in 2017 (Ministry of Health., 2017). Modifiable risk factors associated with cardiovascular disease include physical inactivity (Bushman, 2019), obesity (Buttar, Li, & Ravi, 2005), diabetes (Stehouwer, Henry, & Ferreira, 2008), and hypertension (Buttar et al., 2005; Mitchell, 2014). Cardiovascular disease also increases with age (Alghatrif et al., 2013) and is more likely to occur in men than women (Nishiwaki, Kurobe, Kiuchi, Nakamura, & Matsumoto, 2014; Ogola et al., 2018).

Cardiovascular disease is associated with structural and functional changes in the blood vessel wall which results in decreased vascular distensibility and increased arterial stiffness. Previous research has indicated that the stiffness of the elastic arteries (i.e. the aorta) can independently predict cardiovascular disease risk (Laurent et al., 2007; Laurent et al., 2006; Vlachopoulos, Aznaouridis, & Stefanadis, 2010). In a recent review, Ogola and co-workers showed that people with increased arterial stiffness also increased their chances of developing cardiovascular disease by 48% (Ogola et al., 2018). Researchers have also recommended that the carotid-femoral pulse wave velocity (cfPWV) is the best measure of elastic artery stiffness (Van Bortel et al., 2012). An increase in arterial wall stiffness results in systolic blood pressure increases, causing an increase in the workload of the left ventricle (Westerhof & O'rourke, 1995) and diastolic blood pressure decreases which can impair coronary perfusion (Watanabe, Ohtsuka, Kakihana, & Sugishita, 1993). With the advancement of technology, pulse wave velocity (PWV) can be measured using machines like the SphygmoCor Xcel, and is now a common measure in clinical studies due to its ease of measurement, reproducibility and reliability of results (Elliot, Hamlin, & Lizamore, 2020) along with its close association with cardiovascular disease (Mattace-Raso et al., 2004).

There is a large body of evidence that indicates regular moderate-intensity physical activity is beneficial at reducing the risk of cardiovascular disease (Asmar et al., 2001; Boreham et al., 2004; Butlin & Qasem, 2017; Cortez-Cooper et al., 2008; Goenka & Lee, 2017; Kruse & Scheuermann, 2017; Laurent et al., 2006; Lear et al., 2017; Mcdaniel et al., 2012; Myers et al., 2015; Nishiwaki et al., 2015; Pal et al., 2014; Patil et al., 2015; Yamamoto et al., 2009). The increased shear stress with increased blood pressure during exercise (particularly moderate-high intensity) is thought to help maintain endothelial cell integrity and thereby maintain vessel stiffness (Di-Francescomarino et al., 2009; Kruse & Scheuermann, 2017). Interestingly, a relatively recent study has indicated that stretching exercises increased the arterial compliance by 23% (Cortez-Cooper et al., 2008) which may also be beneficial at maintaining blood vessel health.

In Cortez-Cooper's (2008) study, the authors investigated the use of strength training on cardiovascular health, and reported an unexpected but curious finding. The control group, which practised 30 to 45 min of stretching (3 days/week for 13 weeks) significantly reduced blood pressure (-6 ± 10 mmHg, mean ± SD) compared to the intervention groups, which were a strength training group (completed 30 to 45 min of strength training 3 days/week), and a strength training plus aerobic exercise group (completed 30 to 45 min of strength training 2 days/week, and 30 to 45 min of aerobic training 2 days)(Cortez-Cooper et al., 2008). This study was the first to suggest that low-intensity stretching may have a beneficial effect on cardiovascular health, compared with moderate-to-high intensity aerobic exercise or strength training. A more recent study (Nishiwaki et al., 2015) confirming the results of Cortez-Cooper et al. (2008), reported that 4 weeks of supervised stretching

(30 min each day, 5 days/week) in healthy middle-aged adults resulted in a reduction of arterial stiffness by 4.9 ± 1.6% when compared to the control group who did not stretch. Indeed in a cross-sectional study, a negative relationship has been found between trunk flexibility and brachial-ankle pulse wave velocity (baPWV) (Yamamoto et al., 2009). These unique results indicate that chronic stretching may have a direct beneficial effect on vessel physiology and thereby cardiovascular disease risk. Besides exercise and physical activity, researchers throughout the world are working on identifying a range of risk markers that can predict cardiovascular health incidents in individuals. Some markers such as age, sex, heart rate variability, blood lipid profile, and blood glucose are well researched and are directly associated with cardiovascular health. While others such as flexibility, stretching, and yoga require further attention.

Yoga an ancient Indian system that involves various static and dynamic stretching positions, as well as breathing and relaxation techniques, has been shown to improve flexibility (Farinatti, Rubini, Silva, & Vanfraechem, 2015; Patil et al., 2015; Petric et al., 2014). Yoga has been extensively studied in India (Bhavanani, 2003; Dash & Telles, 1999, 2001; Raju et al., 1986) and has become an accepted exercise modality in the Western fitness industry (Garfinkel & Schumacher Jr, 2000). Two review articles by Raub (2002) and Innes et al. (2005), indicated that yoga produced a beneficial effect on cardiopulmonary function, glucose metabolism and lipid profiles, however, concerns exist over many of the yoga studies to date, due to methodological issues including uncontrolled confounding variables, non-randomization, small sample sizes and lack of suitable control groups (Tracy & Hart, 2013).

To date, there are few experimental studies examining the effect of yoga on arterial stiffness (Cramer et al., 2018; Miles et al., 2013; Patil et al., 2015). For example, Patil et al. (2015) examined the effects of different exercise routines (e.g. yoga 55 min/day 6 days/week versus brisk walking plus stretching 55 min/day 6 days/week) on arterial stiffness in sedentary males aged 60 years and older and found a reduction in brachial-ankle pulse wave velocity by 7.7%, carotid-femoral pulse wave velocity by 7.9%, and augmentation index (AIx) by 8.7% in the yoga group compared to the walking and stretching groups. Considering the possible beneficial effects of yoga on cardiovascular health, it is surprising that there have been only a few cross-sectional studies investigating the influence of yoga on clinical outcomes such as arterial stiffness and blood pressure (Cramer et al., 2018; Miles et al., 2013; Patil et al., 2015). Cross-sectional studies investigate the phenomenon in situ, which is unable to be completed with lab-based studies or interventions. Although such cross-sectional studies cannot illicit cause and effect scenarios, they are useful at uncovering disease associations and important variable associations that may be useful for disease prevention.

Therefore, the purpose of this study was to conduct a cross-sectional study to investigate associations between clinical measures of cardiovascular health and practicing yoga. CfPWV, blood pressure and AIx were measured with other anthropometrical (height, body weight, body fat, body mass index, waist to hip ratio, flexibility), and physical variables (weekly physical activity). Other health (resting heart rate, heart rate variability, lipid profile, glucose metabolism) and stress parameters (perceived stress scale) were also assessed in a group of volunteers, some of who regularly practice yoga and some who do not practice yoga.

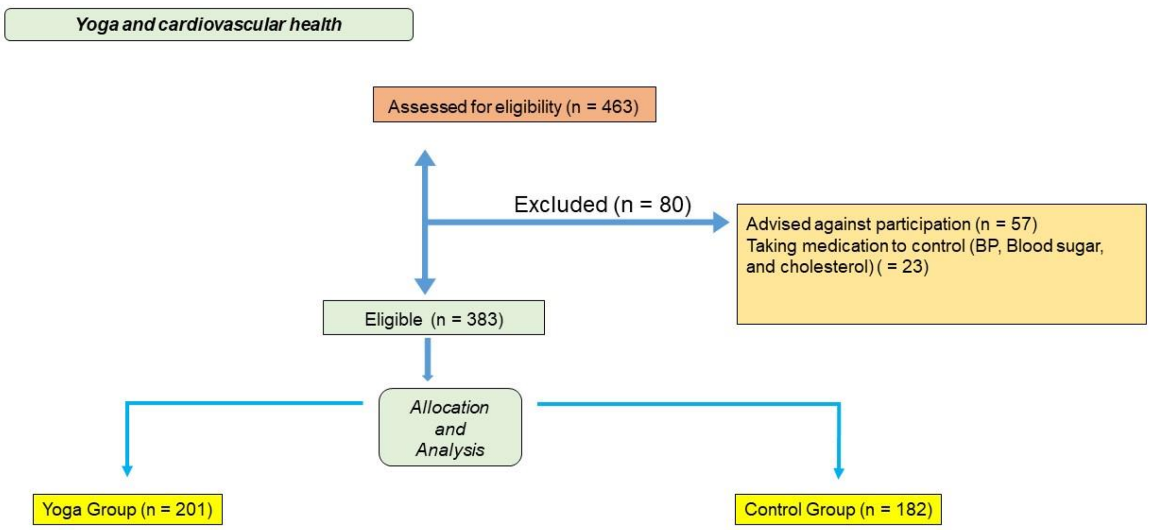
6.4 Methods

A cross-sectional study design was used to investigate the relationships between a change in lifestyle behaviour (i.e. the regular use of yoga) and cardio-metabolic health (i.e. aortic pulse wave velocity) in a sample of New Zealand adults. A magnitude-based inference was used to estimate the sample size required to detect the smallest beneficial (or detrimental) effect in a cross-sectional study (in this case a correlation of 0.16 between sit and reach flexibility and aortic pulse wave velocity in middle-aged adults with the maximum chances of a Type 1 and 2 error set at 5% (i.e. most unlikely), approximately 258 subjects are required. To allow for an approximate 30% non-completion rate across all study measures, 336 subjects (168 per group) were estimated to be recruited for the study.

6.4.1 Participants

A total of 383 adults (18 - 85 years old) participated in the study and were divided into two groups. Participants practising weekly yoga (at least once per week) for more than 12 weeks (yoga group), and participants who had not practised yoga at all in the past 6 months (control group). Participants were recruited using flyers distributed in yoga studios and communities throughout New Zealand. All interested participants were required to complete a medical screening questionnaire prior to participating in the study. Participants were excluded if they had a medical condition, including cardiovascular disease or peripheral disease, or who were recommended against participation by their medical practitioner. Participants who were taking medications to control high blood pressure, high cholesterol, or high blood sugar were also excluded from the study (Figure 3). The procedure, purpose, and risks of being involved in the study were explained to each participant prior to enrolling in the study. All participants gave written informed consent before participating in the study. The study was approved by the Human Ethics Committee of Lincoln University (reference 2018-42).

Figure 3. Flow diagram of contacted participants



6.4.2 Design

Participants were scheduled for a one-hour testing session between January and September 2019 from 5:00 am to 11:30 am. Before testing, candidates were asked to abstain from caffeine on the morning of the test and to undertake overnight fasting from food starting at 10 pm the night prior. Participants were also asked to refrain from heavy exercise 24 hours prior to the test to avoid the acute effects of exercise on vascular parameters measured. Participants answered questionnaires related to their health, perceived stress, and physical activity prior to commencing the physical and clinical assessments.

6.5 Procedures

6.5.1 Stress and physical activity monitoring

Participants were asked to answer two questionnaires related to their physical activity and stress levels prior to the testing session. The International Physical Activity Questionnaire Short Form (IPAQ-SF) was used to assess weekly physical activity levels. IPAQ-SF assesses the intensity of physical activity and the amount of time spent by participants in physical activity as part of their daily lives. The total physical activity was then converted into METmin.week^{-1} and time spent sitting (Cheng, 2016). Participants were categorised into low (≤ 599 METmin.week^{-1}.), moderate (600 ≥ but ≤ 2999 METmin.week^{-1}), and high (≥ 3000 METmin.week^{-1}) activity groups based on weekly physical activity using IPAQ scoring system (Cheng, 2016). Participants also answered the Perceived Stress Scale (PSS) (Cohen, Kamarck, & Mermelstein, 1994), a psychological instrument that consists of 14 questions to measure the perception of stress.

6.5.2 Anthropometric measurements

Upon entering the sport and exercise science lab, each participant's height was measured using a portable stadiometer (Seca 213, Hamburg, Germany) to the nearest 0.1 cm, with shoes and socks removed. Then bioelectrical impedance analysis (Figure 4), Accuniq BC380, SELVAS Healthcare, Inc, Korea) was performed (at frequencies of 5, 50, 250 kz) to assess skeletal muscle mass, total body fat, percentage body fat levels, and body-mass index (BMI). The waist to hip ratio (WHR) data was collected manually, using a retractable tape measure to the nearest 0.1 cm after removing excessive clothing, following the protocol described by Czernichow, Kengne, Stamatakis, Hamer, and Batty (2011). Participants were asked to void their bladders prior to all measurements. All participants were measured and classified according to guidelines described by the World Health Organisation (WHO) (2004).

Figure 4. Bio-impedance analysis

6.5.3 Hamstrings flexibility

The hamstring flexibility of participants was measured in a seated position (Yamamoto et al., 2009) in front of a Flex-Tester© box (Novel Products, Inc.; Rockton, IL). The participants performed the hamstring flexibility without any warm-up. Participants were instructed to keep their knees fully extended in front and the soles of their feet placed against the box. Participants then placed one hand flat on the top of the other hand and pushed the measuring tab of the box in a slow and controlled movement as far as possible and continued breathing as they held their furthest position for two sec (Yamamoto et al., 2009). There was a 2 min rest between each of the three attempts, during which participants could choose to either stand up or sit down and drink water. The best attempt was used in the analysis.

Arterial stiffness

The most common and reliable non-invasive method of measuring arterial stiffness is the assessment of brachial pulse wave analysis (PWA) and carotid-femoral pulse wave velocity using applanation tonometry (Stoner, Young, & Fryer, 2012).

6.5.4 Pulse wave analysis

PWA is a non-invasive method of assessing the ventricular-vascular interaction and can be used as an assessment of endothelial function (Stoner et al., 2012). The augmentation index (AIx) is the ratio of aortic augmented pressure (AP) to aortic pulse pressure (PP) and indicates regional (i.e. aortic) arterial stiffness (Kaibe et al., 2002). Arterial stiffness is assessed based on the augmentation of the pressure wave generated during the systolic anterior motion of the heart (Stoner et al., 2012). It is considered to be an independent risk factor for cardiovascular disease (Kaibe et al., 2002; Laurent et al., 2006). Pulse wave analysis was performed in the supine position and was assessed automatically using SphygmoCor XCEL (AtCor Medical Pty. Ltd., Sydney, Australia) device and software (SphygmoCor XCEL Software Version: 1.2). The PWA protocol developed by Ogedegbe and Pickering (2010) was adapted for the guidance of the branchial cuff placement for the current research intervention (Figure 5). The branchial cuff placement was standardised and used on the left arm of the participants (Figure 5).

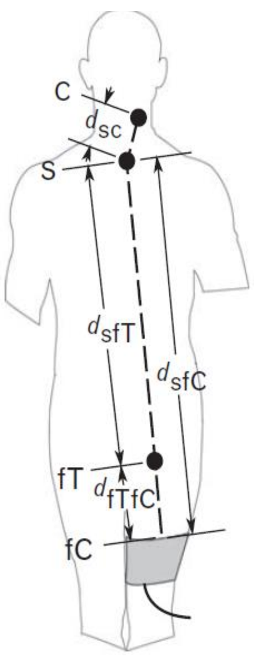
Figure 5. Brachial cuff placement representation, adapted from Ogedegbe and Pickering (2010).

A brachial BP cuff was placed (Figure 5) snugly on the left upper arm over the peripheral brachial artery connected to the SphygmoCor® EXCEL. The participants were asked to rest and relax for 5 min comfortably and to remain in the supine position prior to any measurement. The researcher then started the automatic cuff inflation which lasted approximately 45 s (sphygmoCor XCEL, AtCor Medical Pty. Ltd., Sydney, Australia). During the assessment, the brachial cuff automatically inflates to measure brachial systolic and diastolic pressure, and then automatically deflates and re-inflates after 5 s to capture the PWA waveform. As heart rate has a profound effect on AIx, the AIx was normalized to a heart rate of 75 bpm (AIx75).

6.5.5 Pulse wave velocity

After completing the measurement of PWA and approximately 10 min of passive rest, the carotid-femoral pulse wave velocity (cfPWV) was measured while the participant remained in the supine position. The left carotid artery and left femoral artery were used as the measurement sites for the pulse wave velocity analysis. A direct method of the carotid-femoral protocol described by Butlin and Qasem (2017) was used for the guidance of the femoral cuff pressure and tonometer placement for the current research intervention (Figure 6) while following data collection protocols described by (Elliot et al., 2020).

Figure 6. Femoral cuff pressure and tonometer placement measurement guidelines adapted from Butlin and Qasem (2017).



Prior to the measurement, the researcher located the carotid pulse and then marked the site on the participant’s neck (Figure 7). A femoral blood pressure cuff was attached snugly around the participant’s left thigh (Figure 9) as close to the inguinal crease as possible. Then the researcher also located and marked the femoral arterial pulse on the participant's inguinal crease. The distance between the top of the femoral cuff and femoral artery was measured using a retractable tape measure and entered into the SphygmoCor software.

Figure 7. Marking the carotid pulse.

To minimise measurement error, an infant stadiometer (Figure 8, McCook, U.S.A) which has a fixed-point scale with a moveable head, was used to measure the distance between the marked carotid pulse and the top of the femoral cuff measurement points. This made it possible to measure the direct distance without including measurement error from the excessive chest and abdominal volume when breathing (Figure 10).

Figure 8. Infant stadiometer.

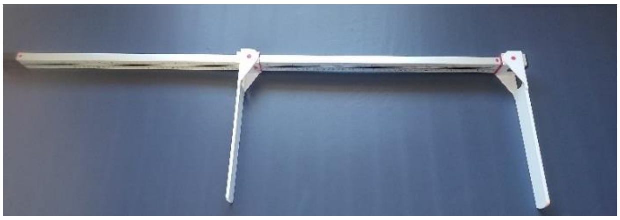


Figure 9. Femoral cuff placement

Figure 10. Distance measured from carotid pulse to femoral pulse area using infant stadiometer.

The SphygmoCor device was set to capture the strongest pulse waveform during the measurement automatically. To standardize recordings and reduce subjectivity, the device was set to automatically capture the pulse wave recording after high-quality waveforms had been recorded during the specified capture time (i.e., 5 s). An ‘automatic capture’ was attempted for a full cuff inflation/deflation cycle, plus the first 20 s of the second cuff inflation. Thereafter, if an automatic capture was unsuccessful but the waveforms appeared to be of sufficient quality to the researcher, a manual capture measurement was taken.

The researcher also indicated whether a manual or automatic measurement was taken during the assessment of carotid-femoral pulse wave velocity. The carotid-femoral pulse wave velocity is considered to be the gold standard for the non-invasive assessment of arterial stiffness (Laurent et al., 2006) as it indicates the velocity of the pulse wave travelling through the aorta. The stiffness of the aorta is directly associated with the pulse wave velocity (Kaibe et al., 2002; Laurent et al., 2006).

The researcher used the pulse wave velocity reference values established by Mattace-Raso et al. (2010) for the analysis Table 10. Thus, the data for inclusion in this research project was required to have a quality-controlled tick from the software. Any manual capture which did not meet the quality control standards was repeated until quality control was met.

Table 10. Pulse wave velocity reference values used for the analysis.

Age	Age Range	Optimal	Normal	High Normal	Grade 1 HT	Grade 2/3 HT
18	18-29	7.6	8.2	8.5	9.2	9.7
30	30-39	8.3	8.5	8.9	9.2	10.2
40	40-49	8.8	9.4	9.9	10.7	12.2
50	50-59	9.6	10.5	11	12	13.1
60	60-69	11.3	12.1	12.9	13.9	15.2
70	70+	13	14.7	14.8	16.1	17.5

Reference values are adapted from Mattace-Raso et al. (2010).

6.5.6 Heart rate variability (HRV)

After finishing the measurements for arterial stiffness, participants were asked to sit on a chair and their sitting height was adjusted to avoid any discomfort that may arise from sitting and possible influence on their heart rate. Heart rate variability was measured during the sitting period at rest, under both spontaneous (5 min) and controlled breathing (5 min) conditions. The breathing pattern was explained to the participants and they were familiarised with the process. During the breathing session, 1 min was given between the change of spontaneous and controlled-breathing conditions. To keep the controlled breathing standardised, audio of recoded instructions was played for all participants. To measure the heart-rate variability and for analysis, a protocol established by Lizamore (2013) was used in the current study. In addition, a breathing frequency of 10 breaths per min was selected for the controlled breathing as this is a comfortable breathing rate for yogis, it is also within the range of the HF band (0.15 – 0.4 Hz), and also is slow enough to prevent incidences of mild hyperventilation, which was observed by Nishiwaki et al., 2014 and Pinna, Maestri, La Rovere, Gobbi, and Fanfulla (2006) in their study, when they paced the breathing rate at 15 breaths/min.

To detect and to record the heart-rate variability data a transmitter belt (Wearlink W.I.N.D, Polar Electro Oy, Kempele, Finland) and, a Polar heart rate (HR) watch (RS800CX, Polar Electro Oy, Kempele, Finland) was used, with the HR watch set to capture RR interval data. Contact electrode gel (Signa Crème®, Electrode cream, Parker Laboratories Inc. Fairfield, New Jersey, USA) was applied to improve skin contact between the electrodes of the transmitter belt and the skin during the data collection process. Furthermore, the data was relayed and stored on an HR watch (RS800CX, Polar Electro Oy, Kempele, Finland). Then the HR data were saved on the HR watch until it could be uploaded (external IrDA USB 2.0) onto a laptop. To analyse the HR data Kubios HRV Standard software (Version 3.2.0) was used. Kubios HRV Standard software (Version 3.2.0) automatically filtered the HR data for ectopic beats using the “error correction” function. Filters were set to the default ‘Moderate’ filter power and Minimum Protection Zone of 6 beats/min^{-1}. Following the filtering process, any remaining ‘spikes’ in the data were manually removed prior to analysis.

For the time domains, the standard deviation of the NN intervals (SDNN) and root mean square of the successive differences (rMSSD) in milliseconds were measured. For the frequency domains, total power (TP, 0.4 Hz, ms2), very low frequency (vLF, 0.04 Hz, ms2), low frequency (LF, 0.04-0.15 Hz, ms2) and high frequency (HF, 0.15-0.4 Hz, ms2) were assessed. The ratio of LF to HF power (LF/HF ratio) of heart-rate variability spectra represents a measure of sympathovagal balance and was also calculated. The LF/HF ratio, normalized LF (nLF = LF/LF + HF), and normalized HF (nHF = HF/LF + HF) through Fast Fourier Transform were also calculated. According to Florea and Cohn (2014) and Acharya, Paul Joseph, Kannathal, Lim, and Suri (2006), the HF represents parasympathetic nervous modulation, LF reflects sympathetic or both sympathetic and parasympathetic nervous activity, while the LF/HF ratio represents a sympathetic balance or sympathetic modulation.

To measure the PNS the Kubios HRV Standard software (Version 3.2.0) used mean inter-beat-intervals (RR interval), root mean square of successive RR interval differences (RMSSD), and Poincaré plot index SD1 (standard deviations perpendicular to and along the line-of-identity of the mean of RR intervals) in normalized units (Berntson et al., 1997; Brennan, Palaniswami, & Kamen, 2001; Electrophysiology, 1996; Yang et al., 1997). For example, a longer mean RR interval means lower heart rate and high values of RMSSD reflects the strong rectified signal average (RSA, computed based on the deceleration and acceleration phases of the RR interval data) component and increased parasympathetic activation. The poincaré plot index SD1 in normalized units (Brennan et al., 2001), calculates the sympathovagal balance by using the LF to HF power ratio from heart rate variability measurements.

To measure the SNS, the Kubios HRV Standard software (Version 3.2.0) used mean HR interval, Baevsky's stress index (SI) (Baevsky, 2009), and Poincaré plot index SD2 (standard deviations perpendicular to and along the line-of-identity of the mean of RR intervals) in normalized units. Since higher heart rate reflects higher sympathetic activity, Baevsky's stress index (SI) reflects the stress of the cardiovascular system by measuring HRV. High values of stress index means high sympathetic activity.

Similar to PNS calculation the Poincaré plot index SD2 uses the LF to HF power ratio from heart rate variability measurements. All the values uploaded in the software are first compared with the normal populations based on the previous research (Brennan et al., 2001; Nunan, Sandercock, & Brodie, 2010). Then the values are scaled with the standard deviations of the normal population. In order to obtain robust and reliable PNS and SNS index values, a proprietary weighting is applied. A positive value indicates the number of SDs above the normal population average, while a negative value indicates the number of SDs below the normal population average on the parameter values (Nunan et al., 2010). The calculation and interpretation of SNS and PNS are similar.

6.5.7 Blood test markers

All blood samples were taken following an overnight fast of food and drink (except water). Participants were in a seated position, with their hands on the examination table with the sample drawn from a pinprick on their fingertip. The finger was sterilised using skin cleansing swabs (Briemarpak®, Australia), and a drop of capillary blood was collected from the fingertip (standard aseptic technique) using a single-use lancet (Unistik® 3, Owen Mumford, Oxfordshire, U.K) which was collected into a 30 *ul* capillary tube (PTS diagnostics, USA). The collected samples were then analysed immediately to determine the total cholesterol and blood glucose concentrations (PTS panels, PTS diagnostics, USA) using a portable analyser (CardioChek PA, Indianapolis, Indiana, USA) and following the clinical guidelines of Dibetesuk (2019) Table 1 and Table 2.

6.6 Statistical analysis

The Statistical Analysis System (Version 9.3, SAS Institute, Cary NC) was used to calculate the mean and standard deviations of the variables. Residuals from the SAS output were initially checked for normality. Differences in variables between the yoga and control groups were determined using unpaired t-tests with an alpha level of $p \leq 0.05$. Since age has an effect on many of the variables (e.g. PWV and BP) the data was also separated into age groups (young = 18-39 years, middle = 40-59 years and old = 60 years and above) to account for changes in the outcome variables with age. Pearson correlations were computed to provide an indication of the overall association between the selected variables. A multiple stepwise linear regression was used to determine the predictors of carotid-femoral pulse wave velocity in all participants. Proc Reg was used in the SAS analysis software with carotid-femoral pulse wave velocity as the dependent variable and age, sex, flexibility, resting heart rate, body fat, skeletal muscle mass, body weight, smoking behaviour, meat consumption, salt intake, alcohol consumption, stress levels BMI, and PA in METS as independent variables. Since cfPWV is highly correlated to other cardiovascular variables (e.g. systolic blood pressure, augmentation index, and pulse pressure), these variables were not included in the model.

The scale of magnitudes developed by Cohen (1988) (i.e. $r < 0.30$ = small, $r = 0.31$-0.5 = moderate, $r > 0.50$ = large) was used to identify which independent variables to include in the model. If the correlation of the model was large an increase of ≥ 0.05 was considered worthwhile. Further analysis were stopped in the model when additional variables were not making a worthwhile improvement in the overall correlation.

6.7 Results

Out of 463 participants, 383 were eligible for this research: 201 in the yoga group and 182 in the control group. The participants who regularly practiced yoga for more than 3 months were added into the yoga group and later included in the matched age group, similarly, participants in the control group were selected on the basis of not being involved in any type of yoga practice in the last six months (to remove any chronic practice effect). Participants who had a medical condition or were advised against participation (n = 57) or others who were taking medications (to control blood pressure, cholesterol, or blood sugar) or had the peripheral arterial disease (n = 23) were excluded from the study “see Figure 3”.

Smallest worthwhile differences were calculated using Cohen’s value of 0.2 of the between-subject standard deviation (Cohen, 1988), for the cardiovascular variables. Also the meaningful clinical important change (MCIC) is given in Table 11 based on previous published work.

Table 11. Calculation of smallest worthwhile and clinically meaningful change in the participants.

Measure of change	SWC	MCIC	Evidence
cfPWV ($m.s^{-1}$)	0.27	1 $m.s^{-1}$	(Wilkinson et al., 2010)
BSBP (mmHg)	2.63	≥ 5 mmHg	(Whelton et al., 2018; Williams
BDBP (mmHg)	1.70	≥ 2.5 mmHg	et al., 2018)

cfPWV: carotid-femoral pulse wave velocity, BSBP: Brachial Systolic Blood Pressure; BDBP: Brachial Diastolic Blood Pressure; SWC; Smallest Worthwhile Change, SRC:. MCIC: Meaningful Clinical Important Change.

Furthermore, to investigate important lifestyle predictors of carotid-femoral pulse wave velocity a multiple stepwise regression was run. The results of the multiple stepwise regression analysis are given in Table 12. Age and sex were the strongest predictors of pulse wave velocity. Other substantial variables that were added to the regression model included RHR, flexibility, physical activity, body weight, eating preference, weekly sitting time, and perceived stress. The correlation between these independent variables and carotid-femoral pulse wave velocity was 0.71 (very large), which taken together can explain 50% of the variance in carotid-femoral pulse wave velocity. The model was cfPWV = 4.135 + (0.0659 x age) + (0.5303 x sex) + (-0.0104 x flexibility) + (0.0219 x resting heart rate)

+ (-0.00002 x physical activity). Where age is decimal years, sex is 1 for females and 2 for males, flexibility is sit and reach score in cm, resting heart rate is in beats per minute and physical activity is in total METmin.week^{-1}.

Table 12. Summary of stepwise selection for forward selection logical regression.

Stepwise Selection Summary							
Step	Effect entered	Number Effects In	Partial R-Square	Model R-Square	Criteria (p)	F value	P > F
1.	Age	1.	0.4281	0.4281	48.507	281.48	<0.0001
2.	Sex	2.	0.037	0.4651	23.168	25.94	<0.0001
3.	RHR	3.	0.0249	0.4900	6.8100	18.22	<0.0001
4.	Flexibility	4.	0.0093	0.4993	1.9508	6.92	0.0089
5.	Met.min^{-1}	5.	0.0041	0.5034	0.8996	3.09	0.794
6.	Body weight	6.	0.0023	0.5057	1.1954	1.73	0.1891
7.	Meat	7.	0.0016	0.5073	2.0292	1.19	0.2770
8.	Sitting	8.	0.0015	0.5088	2.8943	1.15	0.2834
9.	Stress	9.	0.0008	0.5096	4.3066	0.62	0.4303

PWV: pulse wave velocity; 50.96 % of the variation in PWV is explained by adding Age: in years; Sex: female = 1, male =2; RHR: resting heart rate: flexibility: sit and reach test in cm, Met.min-1: weekly physical activity in minutes; body weight: kilograms; eating preference: meat: sitting: time spent sitting weekly in minutes; stress: perceived stress scale score in the model.

6.7.1 General differences between yoga and control groups

Table 13 details the study participants' characteristics. Participants in the yoga group practised yoga on average 3 times a week (ranging from 1 to 7 days a week). The control group was significantly heavier (8.2 ± 4.1 kg, $p < 0.01$), had more muscle mass (2.9 ± 1.5 kg, $p < 0.05$), and taller (2.7 ± 1.7 cm, mean ± 95% CI, $p = 0.002$) than the yoga group. The yoga group's flexibility was significantly (12.7 ± 1.9 cm, $p < 0.01$) higher than the control group. The total physical activity level of the yoga group was significantly higher (1035.1 ± 671.3 METmin.week^{-1}, $p < 0.01$) than the control group. The control group had a higher BMI (2.0 ± 0.7, $p < 0.05$), waist-hip-ratio (0.05 ± 0.02 cm, $p < 0.01$), and body fat (2.9 ± 3.1 kg) than the yoga group.

The control group had a higher blood glucose level compared to participants of the yoga group (1.3 ±2.9 mg/dl), but the yoga group had higher total cholesterol (15.0 ± 8.3 mg/dl). The participants in the yoga group spent significantly less time sitting (331.1 ± 163.6) compared to the control group

(385.8 ± 181.5, p = 0.002). Finally, the yoga group had significantly lower cfPWV (0.13 ± 0.28, $m.s^{-1}$, *p* < 0.05) and SBP (2.04 ± 2.64, mmHg, *p* < 0.05) compared to the control group. However, this improved cfPWV did not meet the smallest worthwhile change or meaningful clinical important change. The autonomic variables during controlled breathing for the control and yoga groups are also presented in Table 13. No significant differences were found between the groups in any of the variables measured.

Table 13. Physical and clinical characteristics of the yoga and control group for cardiovascular health assessment.

	Yoga n = 201	Control n = 182
Age (years)	48.4 ± 14.0	42.7 ± 14.1
Yoga Practice (times per week)	2.8 ± 1.5	0
Height (m)	167.4 ± 7.6	170.1 ± 9.7*
Weight (kg)	67.9 ± 11.6	76.1 ± 14.6*
BMI (kg/m^{-2})	24.0 ± 3.4	26.1 ± 4.4*
WHR	0.80 ± 0.0	0.88 ± 0.1*
Flexibility (cm)	37.0 ± 8.3	24.3 ± 11.0*
Total cholesterol (mg/dl)	192.1 ± 40.5	176.7 ± 42.8*
Blood Glucose (mg/dl)	90.6 ± 13.8	92.0 ± 15.2*
Total Body Fat (kg)	18.3 ± 7.3	21.1 ± 9.6
Body Fat (%)	26.6 ± 8.1	27.5 ± 10.0
Skeletal muscle mass (kg)	27.6 ± 5.1	30.6 ± 6.7*
Perceived Stress Score	27.2 ± 3.2	28.0 ± 3.9
Sitting Time (min)	331.1 ± 163.6	385.8 ± 181.5*
Physical Activity	4062.3 ± 3296.5	3027.1 ± 3379.5*
cfPWV ($m.s^{-1}$)	8.6 ± 1.3	8.7 ± 1.4*
BSBP (mmHg)	118.7 ± 13.0	120.7 ± 13.3*
BDBP (mmHg)	72.8 ± 8.8	73.0 ± 8.0
ASBP (mmHg)	108.7 ± 12.9	109.6 ± 12.7
ADBP (mmHg)	73.6 ± 8.8	73.3 ± 8.0
Pulse Pressure (mmHg)	34.9 ± 6.7	35.8 ± 8.0
Alx 75	22.6 ± 12.7	18.3 ± 15.0
Resting Heart Rate (beats/m)	57.6 ± 8.8	59.0 ± 9.1
LF (nu)	56.24 ± 22.41	56.48 ± 21.37
HF (nu)	43.67 ± 22.33	43.47 ± 21.35
LF/HF Ratio	3.07 ± 6.08	2.71 ± 5.13
PNS	1.46 ± 2.30	1.82 ± 2.44
SNS	-0.59 ± 1.08	-0.60 ± 1.04

Values are means ± SD; *statistically significant between the control and yoga participants (*p* < 0.05), physical activity is $MET\text{-}min.week^{-1}$, cfPWV: carotid-femoral pulse wave velocity, Alx75; augmentation index, LF nu; low frequency neutralized units, HF nu; high frequency normalised units, LF/HF ratio; ratio of low frequency to high-frequency power, PNS index; parasympathetic nervous system index, SNS index; sympathetic nervous system index; Sitting time: weekly sitting time calculated in minutes; BSBP: Brachial Systolic Blood Pressure; BDBP: Brachial Diastolic Blood Pressure; ASBP: Aortic Systolic Blood Pressure; ADBP: Aortic Diastolic Blood Pressure.

In Table 14, the age-adjusted characteristics of the participants are presented. Only middle-aged control participants were taller than their corresponding middle-aged cohort in the yoga group. Interestingly, the control group was heavier across all age groups ($p < 0.01$) and had significantly higher muscle mass in young and middle-aged participants ($p < 0.05$) compared to the yoga group participants. However, the control group had worse cardiovascular risk factors, with significantly higher BMI ($p < 0.05$) and waist-hip ratios ($p < 0.01$) across all age groups, and a higher body fat percentage in the middle and old age group compared to their yoga counterparts. Compared to the control group the yoga group had a significantly higher total cholesterol level but only in the older age group (29.34 ± 19.01 mg/dL, mean ± 95% CI, $p < 0.05$).

Table 14. Means and standard deviations of physical and clinical characteristics classified by age groups in yoga and control participants.

	Control Group			Yoga Group		
	Young n = 87	Middle n = 69	Old n = 25	Young n = 61	Middle n = 96	Old n = 45
Height (cm)	170.64 ± 9.46	170.60 ± 9.84	167.14 ± 10.67	168.31 ± 7.84	167.15 ± 7.96*	166.96 ± 6.97
Weight (kg)	74.87 ± 15.12	78.00 ± 14.97	75.57 ± 12.21	66.71 ± 12.20*	68.59 ± 11.80*	68.15 ± 10.76*
WHR	0.84 ± 0.09	0.91 ± 0.09	0.95 ± 0.10	0.79 ± 0.06*	0.84 ± 0.08*	0.85 ± 0.08*
BMI (kg/m^2)	25.50 ± 4.41	26.65 ± 4.73	26.92 ± 3.12	23.35 ± 3.22*	24.47 ± 3.71*	24.32 ± 2.91*
Flexibility (cm)	25.73 ± 10.49	23.54 ± 11.35	21.69 ± 11.81	37.83 ± 9.04*	37.05 ± 7.71*	36.02 ± 8.80*
Body fat (%)	25.30 ± 1.15	27.03 ± 0.92	27.66 ± 1.34	26.11 ± 0.10	28.52 ± 1.08	29.80 ± 1.80
SMM (kg)	30.63 ± 6.58	30.93 ± 6.93	29.66 ± 6.78	27.77 ± 5.45*	27.77 ± 5.09*	27.38 ± 5.06
Cholesterol(mg/dl)	165.33 ± 43.89	186.64 ± 41.11	189.04 ± 33.81	166.85 ± 31.8	196.08 ± 39.58	218.38 ± 33.45*
Glucose (mg/dl)	88.94 ± 13.00	94.86 ± 16.88	94.88 ± 16.55	87.97 ± 13.21	90.16 ± 14.46*	95.31 ± 12.21
PSS	28.62 ± 4.17	27.67 ± 3.03	27.16 ± 4.62	27.89 ± 3.13	27.49 ± 3.17	25.91 ± 3.43
Physical Activity	3407.49 ± 3425.30	2574.63 ± 3150.31	2952.62 ± 3792.01	3813.79 ± 2966.19	3453.61 ± 2724.57*	5697.79 ± 4241.32*
LF (nu)	56.27 ± 20.72	57.64 ± 22.47	53.93 ± 21.10	55.82 ± 22.00	58.53 ± 22.66	51.98 ± 22.25
HF (nu)	43.69 ± 20.71	42.31 ± 22.45	45.97 ± 21.03	44.13 ± 21.98	41.37 ± 22.56	47.91 ± 22.14
LF/HF Ratio	2.82 ± 6.57	2.87 ± 3.70	1.89 ± 2.02	2.69 ± 4.49	3.87 ± 7.82	1.91 ± 2.62
PNS index	1.57 ± 2.29	1.99 ± 2.68	2.20 ± 2.25	1.52 ± 2.30	1.48 ± 2.27	1.35 ± 2.39
SNS index	-0.53 ± 1.08	-0.65 ± 0.94	-0.72 ± 1.16	-0.61 ± 0.96	-0.63 ± 1.05	-0.47 ± 1.31

Values are means ± SD. *statistically significant between equivalent age groups in the control and yoga participants ($p < 0.05$). Age groups are young 18 - 39, middle 40 - 59, and old 60+, SMM: skeletal muscle mass, Cholesterol: total cholesterol, Glucose: blood glucose, PSS: Perceived Stress Score, physical activity is in METmin.week^{-1} cfPWV: carotid-femoral pulse wave velocity, Alx75; augmentation index, LF nu; low frequency neutralized units, HF nu; high frequency neutralized units, LF/HF ratio; ratio of low frequency to high frequency power, PNS index; parasympathetic nervous system index, SNS index; sympathetic nervous system index.

6.7.2 Cardiovascular differences between yoga and control groups when accounting for age

The yoga group had statistically significant lower brachial systolic blood pressure in the young and older age groups (4.0 ± 3.9 mmHg, mean ± 95% CI in young, 5.9 ± 5.8 mmHg in old, $p < 0.05$), but not in the middle-age group between yoga and control participants (3.0 ± 3.7 mmHg, $p = 0.10$) (see Table 15). In general, the cardiovascular measures were similar between equivalent age groups in the yoga and control participants, except for pulse pressure which was significantly lower in the older yoga participants compared to their similar-aged controls. Similarly, the carotid-femoral pulse wave velocity was lower in the yoga participants compared to the controls in all age groups but reached statistical significance only in the younger and older age groups "see Table 15".

Table 15. Cardiovascular parameter means and standard deviations classified by age groups in the yoga and control participants.

	Control Group			Yoga Group		
	Young n = 87	Middle n = 69	Old n = 25	Young n = 61	Middle n = 96	Old n = 45
BSBP (mmHg)	116.68 ± 10.54	120.84 ± 11.76	134.72 ± 16.53	112.64 ± 11.19*	117.83 ± 10.57	128.84 ± 14.27*
BDBP (mmHg)	70.17 ± 7.37	75.03 ± 7.40	77.24 ± 7.84	68.59 ± 9.27	73.41 ± 7.71	77.31 ± 8.18
ASBP (mmHg)	104.05 ± 9.77	111.19 ± 10.62	124.24 ± 14.09	100.84 ± 10.73	108.39 ± 9.94	120.11 ± 12.92
ADBP (mmHg)	70.86 ± 7.47	75.70 ± 7.38	78.28 ± 8.15	69.44 ± 9.40	74.13 ± 7.60	78.09 ± 8.14
PP (mmHg)	33.16 ± 5.94	35.58 ± 5.92	45.96 ± 11.04	31.39 ± 4.87	24.36 ± 4.89	41.27 ± 7.99*
AP (mmHg)	5.02 ± 4.02	9.65 ± 5.05	15.32 ± 7.18	4.41 ± 3.15	9.31 ± 3.92	14.20 ± 5.78
Alx 75	10.71 ± 11.92	23.55 ± 13.96	30.16 ± 13.06	11.97 ± 10.26	25.19 ± 10.50	31.69 ± 9.97
RHR(beats/m)	60.14 ± 9.97	58.77 ± 7.52	56.36 ± 9.74	58.51 ± 10.10	57.69 ± 8.34	56.53 ± 7.93
cfPWV ($m.s^{-1}$)	8.07 ± 0.98	9.08 ± 0.98	10.64 ± 1.76	7.54 ± 0.90*	8.87 ± 0.92	9.77 ± 1.39*

Values are means ± SD. *statistically significant between equivalent age groups in the control and yoga participants ($p < 0.05$). Age groups are young 18 - 39, middle 40 - 59, and old 60+. BSBP; brachial systolic blood pressure, BDBP; brachial diastolic blood pressure, ASBP; Aortic systolic blood pressure , ADBP; Aortic diastolic blood pressure, PP; pulse pressure, AP; augment pressure, Alx75; augmentation index, RHR; resting heart rate, cfPWV; carotid-femoral pulse wave velocity.

6.7.3 Effect of yoga dosage

Although a moderate association between yoga dosage (number of yoga sessions attended per week) and flexibility was found in the yoga participants (r = 0.36, p < 0.001), the correlation between yoga dosage and the cardiovascular variables ranged from small (AIx75 and yoga dosage r = 0.13, p = 0.06) to trivial (carotid-femoral pulse wave velocity and yoga dosage r = 0.07, p = 0.34). To investigate whether age had any effect on these associations, and based on the recommendations of Alghatrif et al. (2013) the same variables were correlated for the participants after separating them into under and over 50 year olds. Interestingly, the yoga dosage for both below and above 50 years of age was moderately correlated to improved flexibility ($r = 0.33$, $P < 0.001$ and $r = 0.39$, $p < 0.001$, respectively), but not with carotid-femoral pulse wave velocity ($r = 0.01$, $p = 0.89$ and $r = 0.01$, $p = 0.98$) or AIx75 ($r = 0.09$, $p = 0.37$ and $r = 0.06$, $p = 0.50$) respectively.

6.7.4 Cardiovascular differences between yoga and control participants when accounting for age and physical activity

After separating participants based on age and physical activity levels, it was evident that yoga participants had a number of risk factors that were different to the control group (Table 16). Meaningful lower blood pressure was observed among yoga participants in the low physical activity group across all age groups. Furthermore, the old age yoga participants in the moderate and high physical activity group also had meaningful lower systolic and diastolic blood pressure. The pulse pressure of old age moderately active participants of the yoga group was also significantly lower than the control counterpart. Whereas the middle age moderately active participants had significantly lower Alx to their counterparts, but not clinically meaningful.

The cfPWV ($m.s^{-1}$) of the yoga participants across all ages was also lower compared to their control counterparts. In particular, older active yoga participants has a statistically significant and clinically meaningful lower cfPWV ($m.s^{-1}$) compared to their similarly active control counterparts. In contrast, compared to controls, the low activity yoga groups across all ages, had clinically worthwhile lower PWV values, but these differences did not reach statistical significance. Similarly, the young moderate and highly active yoga participants had clinically worthwhile lower PVW values compared to controls, but again, these difference's did not meet statistical significance.

Table 16. Cardiovascular differences between yoga and control participants when accounting for age and physical activity.

	Yoga Group									Control Group								
	Young			Middle			Old			Young			Middle			Old		
	low (n=4)	mod (n=16)	high (n=41)	low (n=14)	mod (n=32)	high (n=50)	low (n=4)	mod (n=8)	high (n=33)	low (n=17)	mod (n=29)	high (n=41)	low (n=20)	mod (n=24)	high (n=25)	low (n=7)	mod (n=10)	high (n=8)
Brachial SBP	108.0	114.0	112.6	118.8	114.7	119.6	131.5	134.8	127.1	117.1$^{\#}$	118.2	115.4	124.0$^{\#}$	117.9	121.1	141.3$^{\#}$	132.1	132.3$^{\#}$
Brachial DBP	66.3	72.1	67.5	72.0	71.5	75.0	74.8	80.8	76.8	72.2$^{\#}$	72.6	67.6	76.7$^{\#}$	73.8	74.9	82.3$^{\#}$	73.8$^{\#}$	77.1
Aortic SBP	97.8	103.3	100.2	108.9	105.2	110.3	121.0	125.6	118.7	105.7$^{\#}$	106.1	101.9	114.9$^{\#}$	109.0	110.3	130.9$^{\#}$	121.2	122.3
Aortic DBP	67.5	72.6	68.4	72.8	72.4	75.6	75.25	80.8	77.7	73.0$^{\#}$	73.3	68.3	77.4$^{\#}$	74.5$^{\#}$	75.5	83.7$^{\#}$	74.8$^{\#}$	77.9
PP	30.3	30.6	31.8	35.9	32.9	34.6	45.8	40.3	40.9	31.7	32.7	33.7	37.5	34.5	35.1	47.2	46.4*	44.4
AP	6.0	5.1	3.98	10.2	8.6	9.5	12.8	16.0	13.9	7.1	5.3	3.9	11.5	10.2	7.7	17.7	14.5	14.3
AIx75	21.5	15.0	9.9	24.7	23.9	26.1	23.0	35.6	31.8	18.9	12.5	5.9	29.7	26.1	16.2*	36.1	28.2	27.4
HR (beats/m)	61.0	58.6	58.2	58.3	61.5	55.1	55.3	59.6	55.9	63.9	58.9	59.5	59.2	61.8	55.5	58.7	58.3	51.9
cfPWV (m.s^{-1})	7.6	7.9	7.4	8.9	8.8	8.9	9.2	10.4	9.71	8.3^	8.27^	7.8^	9.3^	9.0	8.9	10.5$^{\#}$	10.5	11.1*$^{\#}$

*Statistically significant results between equivalent age groups in the control and yoga participants ($p < 0.05$). $^{\#}$Clinically meaningful change between equivalent age groups in the control and yoga participants; ^Smallest worthwhile change between equivalent age groups in the control and yoga participants Age groups are young 18 - 39, middle 40 - 59, and old 60+. Physical activity groups are low (≤599 METmin.week^{-1}), moderate (≥ 600 but ≤2999 METmin.week^{-1}), and high (≥3000 METmin.week^{-1}). SBP; systolic blood pressure, DBP; diastolic blood pressure, PP; pulse pressure, AP; augmented pressure, AIx75; augmentation index, HR; Resting Heart Rate, cfPWV: carotid-femoral pulse wave velocity. SBP, DBP, PP, AP are measured in millimetres of mercury (mmHg)

6.8 Discussion

6.8.1 General findings

There is an overwhelming agreement in the literature over the last half-century that physical activity provides cardiovascular health benefits (Bhella et al., 2014; Lankhorst et al., 2015; Simon, 2018; Woolf & Bisognano, 2011). In the last few decades, a considerable amount of research has supported the belief that physical activity must be of moderate to high intensity (Massicotte & Macnab, 1974; Savage et al., 1986; Tremblay, Simoneau, & Bouchard, 1994) to receive any health benefit. However, the present study shows that a low to moderate intensity stretching exercise routine (such as yoga) may be associated with significant and positive effects on various cardiovascular and physical health indices in adults across all age groups.

Moreover, an association was found between those practising yoga and improved flexibility. The positive effects of yoga complement the results of previous studies evaluating the effects of stretching exercise on flexibility and arterial stiffness in adults (Bisconti et al., 2020; Cramer et al., 2018; Patil et al., 2015). Previous studies have also found a significant improvement in contributing risk factors of arterial stiffness such as systolic blood pressure and pulse pressure as a response to yoga-based stretching (Cramer et al., 2018; Miles et al., 2013; Nishiwaki et al., 2015), suggesting that yoga stretching has the potential to reduce the chances of cardiovascular disease in adults.

The regression analysis predicted a 0.06 unit increase in carotid-femoral pulse wave velocity with each year increase in age. Age is strongly associated with arterial stiffness and cardiovascular disease compared to other risk factors (Alghatrif et al., 2013). A study that compared older (80 years and above) and younger (minimum age 2 years old) participants reported that older adults had a 91% increase in the carotid pulse pressure, a 67.5% increase in the radial pulse pressure wave, and a 50.1% increase in the femoral pulse pressure wave (Kelly, Hayward, Avolio, & O'rourke, 1989). The increases observed in Kelly et al. (1989) study were due to changes in the carotid wave characteristics as one ages.

In the current study, overall the carotid-femoral pulse wave velocity of participants of the yoga group was lower than the control group (Table 13). When the participants were classified by age, the trunk flexibility was significantly higher in the yoga group across all age categories compared to the controls (Table 14). Moreover, when the cardiovascular parameters were classified by age, the carotid-femoral pulse wave velocity of the yoga group was significantly lower in young and older-aged participants (Table 15), and although the carotid-femoral pulse wave velocity of middle-age participants was not statistically significant between groups, it was still lower than the middle-age participants in the control group.

The regression model predicted a decrease of 0.01 in carotid-femoral pulse wave velocity with each cm increase in trunk flexibility. These results are consistent with those of Yamamoto et al. (2009), who showed that increased trunk flexibility is negatively associated with carotid-femoral pulse wave velocity. Healthy adults with high flexibility are shown to have significantly better arterial compliance than low-flexibility adults (Nishiwaki et al., 2014). Furthermore, in a recent study, a 4-week stretching intervention improved flexibility and reduced arterial stiffness in healthy middle-aged males (Nishiwaki et al., 2015). Previous studies have also evaluated the effects of stretching exercise on arterial stiffness, observing consistent results and reporting that improved flexibility improves carotid-femoral pulse wave velocity and brachial-ankle pulse wave velocity (Nishiwaki et al., 2015; Patil et al., 2015; Yamato et al., 2016). The results of the current study are consistent with Bisconti et al. (2020), Yamato et al. (2016), and Shinno et al. (2017) highlighting the capabilities of regular stretching routines such as yoga for improving flexibility, and perhaps thereby reducing arterial stiffness.

The regression model also predicted a decrease of 0.02 in carotid-femoral pulse wave velocity for every unit decrease in HR. Since heart rate is closely associated with cardiac output which is the main driver of systolic blood pressure it seems logical that HR influences PWV. As HR decreases, systolic blood pressure decreases, which reduces PWV (Pierre, Christine, Michel, Alain, & Hugues, 2002; Reimers, Knapp, & Reimers, 2018). Similar to the current study, Bharshankar, Bharshankar, Deshpande, Kaore, and Gosavi (2003) tested healthy yogis aged 40 years and above for various cardiovascular parameters and found a significant reduction in resting heart rate, and systolic BP in yogis when compared to the controls. It is possible that yoga itself enables a reduction in the sympathetic drive (Javorka, Zila, Balhárek, & Javorka, 2002) and thereby reduces HR and subsequently BP and PWV. A reduction in sympathetic activity may also contribute to vasodilation and therefore reduced BP and ultimately PWV (Hotta et al., 2018; Hotta et al., 2013; Jia, Aroor, Jia, & Sowers, 2019). However, there was no evidence observed in the current study for any significant difference in the resting heart rate of the yoga group compared to the control group across all ages.

Physical inactivity is a modifiable risk factor for cardiovascular disease (Ahmed, Blaha, Nasir, Rivera, & Blumenthal, 2012; Perk et al., 2012). The regression model predicted a decrease of 0.00002 in carotid-femoral pulse wave velocity with each unit increase in METmin.week^{-1} (or approximately a drop of 0.08 m.s^{-1} pulse wave velocity, with the average weekly physical activity recorded in the yoga group of 4062 METmin.week^{-1} or 67.7 METhours.week^{-1}). While most of the research linking physical activity with positive cardiovascular health has been completed on mainly chronic aerobic-type moderate-to-high intensity exercise, recently low-intensity exercise like yoga and stretching has also shown good cardiovascular health outcomes (Patil et al., 2015; Perk et al., 2012; White, Gabriel, Kim, Lewis, & Sternfeld, 2015).

In the last two decades, western societies have adopted yoga as a popular way to gain fitness benefits because of its simple and easy to follow stretching routines (Douglass, 2008; Farinatti et al., 2015). In a longitudinal study on healthy and physically active male and female adults, where the carotid-femoral pulse wave velocity was assessed on multiple occasions and physical activity levels were monitored over 25 years, the authors reported that higher levels of weekly physical activity (METmin.week^{-1}) were associated with a slower rate of aortic stiffening (-0.02, $p < 0.05$) Ahmadi-Abhari et al. (2017). Similar to findings from Ahmadi-Abhari et al. (2017), the yoga participants in the current study had a significantly higher level of physical activity ($p < 0.05$, Table 13) and significantly lower carotid-femoral pulse wave velocity, particularly in the young and older age groups.

6.8.2 Stretching and flexibility

Stretching routines are commonly used by trainers to improve athlete flexibility (Fletcher & Jones, 2004), however, it is debatable what stretching type (static or dynamic) is more effective in improving flexibility (Paradisis et al., 2014; Sayers et al., 2008; Shrier, 2004). Meanwhile, yoga is fundamentally very different from any other stretching or physical exercise routine. Yoga incorporates self-awareness, involves moving through a sequence of postures to stretch the body together with breathing exercises and promotes harmonious development of the mind and the body (Manchanda, 2014; Miles et al., 2013). However, improved flexibility is one of the major benefits of yoga practice observed in the current study and yoga has been shown to have similar effects compared to stretching exercises. For example, Gothe and Mcauley (2015) found that 8 weeks of yoga had a similar improvement in flexibility of sedentary healthy older adults compared to stretching plus strength training.

Several studies have shown that yoga has a beneficial effect on the mind and the body by inducing mechanical (Gothe & Mcauley, 2015), neural (Reimers et al., 2018; Tyagi & Cohen, 2016), and hormonal (Kanaya et al., 2014) changes. Thus, the distinctive combination of stretching, breathing, and meditation exercises may have produced an advantage to the yoga group in the current study. Applying mechanical stress when stretching may change the length of the surrounding tissue, with the mechanical stress possibly improving arterial compliance (Jufri, Mohamedali, Avolio, & Baker, 2015; Yamamoto et al., 2004). Improved arterial compliance is observed in both humans and animals after applying mechanical stress (Garry et al., 2007; Hilscher et al., 2019; Jufri et al., 2015). The stretch response activated by the muscle and surrounding tissue may increase secretion of nitric oxide (NO) (Hilscher et al., 2019) in the general area of the stretch as witnessed in human (Sugawara et al., 2004), and animal studies. Increased NO levels affect the local blood vessels resulting in vasodilation and lowered vascular resistance (Hotta et al., 2018; Hotta et al., 2013; Jia et al., 2019) thereby improving PWV. It is understood that a combination of stretching, breathing, and meditation is difficult to study altogether. While the current study may not prove that increased flexibility through stretching alone is responsible for the improvements observed in the yoga participants, it does support evidence from literature and highlights the potential of a stretching routine such as yoga in improving cardiovascular health.

6.8.3 Neural

Another mechanism that helps to explain the changes in PWV with stretching involves the autonomic nervous control of blood vessels (Reimers et al., 2018; Tyagi & Cohen, 2016; Wong et al., 2017; Yamamoto, 2017). For example, Wong et al. reported a decrease in sympathetic and an increase in parasympathetic neural tone after 8 weeks of stretching exercises in postmenopausal women (50 min of stretching per day and 3 days per week) (Wong et al., 2017). Such changes may also affect the nervous activation of blood vessels (Gladwell et al., 2005) which would result in vasodilation, reduced systolic blood pressure and possibly lower PWV. Regular stretching exercises have been shown to positively influence the mechanosensitivity across the neural tissues (Baxi, Mokashi, Borade, Palekar, & Panse, 2017; Butler & Coppieters, 2007) which may increase neural activity and thereby subsequent smooth muscle activation resulting in vasodilation lower BP and PWV. However, the autonomic nervous activity of the heart in the subjects (yoga or control) of this study was measured via heart-rate variability and no difference was found between groups. A possible limitation to the heart-rate variability results of the current study is that heart-rate variability is normally measured and reported as a change over time because of its variability, whereas in the current study it was conducted as a one-off measurement which can be influenced by several confounding variables (psychological stress, diet, previous exercise etc.).

Yoga has the potential to influence the autonomic function via changes in breathing and has been the subject of investigation for many years (Khalsa, 2004; Monika, Singh, Ghildiyal, Kala, & Srivastava, 2012; Patil et al., 2015; Tyagi & Cohen, 2016). These researchers suggest yoga improves autonomic regulation and enhances vagal dominance (Monika et al., 2012), which may assist in the management of many stress-related disorders (Khalsa, 2004). However, similar to the heart-rate variability results, in this study, little difference was observed in the stress levels of the two groups which suggests any changes in PWV in the yoga group is probably not related to altered autonomic nervous activity or stress levels. Discrepancies between studies in terms of participant's age and sex as well as methodological differences in posture and breathing patterns during heart-rate variability measurements may account for the contrasting results. Further research is required in a longitudinal study with repeated measurements to elucidate what changes to autonomic nervous activity occur as a result of training and how these changes influence PWV.

6.8.4 Metabolic

Resting blood glucose is a common measure used to indicate metabolic problems. In the current study, the fasting blood glucose levels were within healthy ranges for both the control and yoga groups (i.e. below 99 mg/dl) (Dibetesuk, 2019). The yoga group had a significantly lower blood glucose level compared to the control group. The low blood glucose level of yoga participants in the current study are similar to Park (2015), Patil et al. (2015) and Gurudut and Rajan (2017). Human (Newsom, Everett, Hinko, & Horowitz, 2013) and animal studies (Marshall et al., 2013) have shown that low-intensity exercise training is sufficient enough to alter insulin and receptor levels and thereby improve blood glucose concentration. It was speculated that the change observed in resting blood glucose levels in the yoga participants of this study are due to an increased insulin sensitivity that comes with regular physical activity (Bird & Hawley, 2017; Kanaya et al., 2014; Subinsolomen, Agarwal, Aaron, & Pradeep, 2015). Such results indicate that again, physical activity may not have to be high intensity to benefit metabolic processes in the body that improve health.

6.8.5 Physical activity and pulse wave velocity

A seemingly obvious reason as to why the yoga group had better PWV values is that the yoga group, on the whole, was more physically active. When taking the overall physical activity values into account, the yoga group completed approximately 30% more physical activity. Previous research has consistently reported that physical activity is inversely associated with PWV (Woolf & Bisognano, 2011). To account for the effect of physical activity on PWV in the current study participants were separated into physical activity groups according to the IPAQ-SF guidelines. Little difference was observed between the yoga and control groups in any of the variables except for a significant difference in carotid-femoral pulse wave velocity of the older but highly active group. In older participants who are highly active, it seems yoga had an added benefit over and above physical activity per se that may contribute to improved vascular function. The results of current study are more or less consistent with Cameron and Dart (1994) and Tanaka et al. (2000), who found that physical activity increases arterial compliance across age groups. Current results also align with existing literature with a possibility of reducing the chances of cardiovascular mortality by increasing physical activity levels (Goenka & Lee, 2017; Nelson et al., 2007; Talbot, Morrell, Fleg, & Metter, 2007).

6.8.6 Dose-response

Previous research has indicated a dose-response relationship between yoga and cardiovascular health (i.e. 24-hour blood pressure) Cramer et al. (2018) or PWV Patil et al. (2015) which may help provide answers as to why improvement was observed in PWV in some yoga groups. To investigate whether there might be a dose-response in the current study, Pearson correlation analysis was conducted between the number of yoga sessions per week (1 – 9), hip flexibility and carotid-femoral pulse wave velocity. A moderate to high correlation between yoga sessions and flexibility ($r = 0.36$, *p*, 0.001) was found indicating that the more sessions of yoga per week the greater the overall hip flexibility.

However, the correlation between yoga sessions and carotid-femoral pulse wave velocity was small ($r = -0.01$) and non-significant ($p = 0.88$). Because age has a large effect on PWV and previous studies (Alghatrif et al., 2013; Cramer et al., 2018; Kelly et al., 1989) have used different age groups to those in this study, a partial correlation was also completed taking age into effect and found little change in correlations ($r = 0.36$, $r = -0.01$ for yoga sessions per week and flexibility or cfPWV respectively). The data suggests that the more yoga sessions you complete per week the better your hip flexibility but you may not necessarily improve your carotid-femoral pulse wave velocity.

The lack of a dose response finding in the carotid-femoral pulse wave velocity may be associated with a number of factors. Firstly, the number of yoga sessions per week was reported by the participants of the yoga group however the objective intensity of each session would have been more informative. Higher intensity sessions would likely result in higher metabolic demand and perhaps a higher metabolic and cardiovascular effect. Secondly, the duration of each yoga session was not asked for in the current study, and there is evidence that longer duration sessions result in better outcomes (Cramer et al., 2014). Thirdly, there are many styles of yoga that range from being very active and dynamic to more slow-paced and less active, which could vary the intensity of the yoga session and may affect participants differently and therefore adaptations and benefits of the yoga on the participants' cardiovascular health. Since, in the current study, participants were not asked to specify the particular style of yoga they were practicing, it was difficult to identify possible intensity differences between yoga practices reported by the participants.

The stepwise multiple regression analysis revealed that the association between PWV, age, flexibility, physical activity, and HR were independent of other lifestyle variables. Variables such as time spent sitting, bodyweight, and perceived stress score, when added to the regression model, did not increase the strength of the associations reported in the current study. Collectively, these findings suggest that yoga-based stretching exercises may increase overall flexibility and reduce the age-related reduction in arterial compliance. However, it was clear that the yoga group was more physically active and spent less time sitting in general compared to the control group, therefore the benefits of yoga other than being highly active are difficult to elucidate. Although the associations reported in the current study are significant, they should be interpreted with caution until studies with larger sample sizes are conducted.

6.9 Conclusion

The present study highlights and is consistent with the current evidence on the chronic cardiovascular and arterial response associated with yoga. Findings from the study suggest that skeletal muscular stretching performed through yoga postures helps to improve flexibility in general, but benefits older participants more compared to others. However the mechanisms for this improved vascular health in older individuals warrants more investigation, but undoubtedly the improvements are linked with increased physical activity levels.

6.10 Study Limitations

The participants in the control group seemed to be physically active, and possibly were somewhat aware of their health and few were completely sedentary, which may have impacted the interaction between groups. Another limitation in the current study is the self-reporting of physical activity over the past week. The error in subjective reports of physical activity is that it relies on the memory of the participants, which may not correctly represent their lifestyle in general. The literature suggests that physical activity is commonly over-reported (Brenner & Delamater, 2014). Furthermore, not including the style of yoga practiced by the participants limited the calculation of cardio-metabolic demands related to yoga practice.

Chapter 7 Final discussion and conclusion

Being active and undertaking regular exercise plays a vital role in both athletes' and non-athletes' lives by either improving or maintaining their performance and health. Yoga is rapidly emerging as an alternative, low-intensity exercise routine for people of all ages. It has been demonstrated that regular yoga practice improves flexibility, muscular performance (Halder, Chatterjee, Pal, Tomer, & Saha, 2015; Tran et al., 2001), cardiovascular health, and blood pressure when compared to individuals who do not practise yoga (Balaji, Varne, & Ali, 2012; Patil et al., 2015). Yoga postures are a unique combination of muscle activation and muscle lengthening which affects every major muscle group of the body. The adaptability of yoga postures makes it suitable even for those people who have joint pain, injuries, are overweight and have other issues preventing them from undertaking higher intensity and higher impact physical activities. The overarching thesis aim was to determine the effect of yoga on sports performance in athletes and cardiovascular health in the general adult population.

Initially, gaps were found in the literature around the use of yoga for enhancing sports performance and improving cardiovascular health (chapter 1). From this research, one cross-sectional study and three intervention studies were planned aiming to address the gaps in the literature. Below is a summary of the findings and how they fit into the current literature.

7.1 Effects of a 12-week yoga intervention on postural sway in male rugby union players.

The findings of this portion of this thesis research related to the improvement of balance. Several studies have investigated the response of balance to strength and balance exercise routines in a non-athletic population, but not yoga. The first study (chapter 3) sought to contribute to this question. This is the first research that has demonstrated an improvement in the balance following a 12 week yoga intervention in rugby players. Additionally, this is the first time the effects of a yoga intervention were measured when rugby players practised yoga alongside their regular rugby training.

Based on the findings of study 1, yoga has the potential to reduce postural sway when practised during the rugby season, however, it was unclear why the changes were only significant in 2-legged eyes closed antero-posterior and medial-lateral directions.

7.2 Association between hamstring flexibility and sprint speed after 8 weeks of yoga in male rugby union players.

The second study (chapter 4) used the results of study 1 that found yoga practised over 12 weeks in conjunction with normal rugby training may improve balance. While we found that yoga may improve some measures of balance there is also considerable literature that suggests yoga can improve flexibility (Farinatti et al., 2015; Gothe & Mcauley, 2015), albeit very little among rugby players. Therefore study 2 aimed to investigate the effect of yoga on flexibility and sprint ability in rugby players.

The novel findings of study 2 were that male rugby players had a very minimal loss of flexibility and performance compared to the control group during the season. Although, there was no significant improvement observed in rugby players' sprint performance. One hour twice a week over an 8 week period of yoga practice was sufficient enough to buffer any loss of hamstring flexibility in male rugby players compared to players who did not complete yoga. This maintenance of flexibility was not related to improved sprint performance in these players. Interestingly, however, the control group significantly decreased their sprint performance as well as flexibility.

Although flexibility did not improve above baseline measures after the 8 weeks of yoga in the males in study 2, no adverse effects were observed. Perhaps it was possible that the study may have had different outcomes if the intervention was practised for a longer (more than 8 week) period. Also, because the yoga session was added into the players' already busy schedule and it was difficult to maintain motivation for players to come to all sessions. Additionally, the non-attendance rate was more than 40% for some of the players. Perhaps if a shorter yoga session (perhaps 30 min rather than 60 min) would fit the time commitments of the players better, and result in fewer drop-outs and greater motivation to complete the sessions. Therefore, study three (chapter 5) was designed to understand whether a longer yoga routine (12 week) with a shorter duration of 30 min would have similar effects on female rugby players' flexibility and sprinting ability.

7.3 Association between hamstring flexibility and 20-m sprint speed after 12 weeks of yoga in female rugby union players

Based on the findings of studies 1 and 2, it was observed that yoga had the potential to improve balance and maintain flexibility and sprint performance of rugby players. In study 3, the intervention was increased to 12 weeks, with a shorter session duration (30 min), with slightly different yoga poses also used. The novel findings in this part of the thesis (chapter 5) demonstrated a 29 degree improvement in flexibility in SLR and a 10% improvement in 5 m sprinting ability. This is the first research to investigate the effects of yoga on female rugby players and the first to demonstrate a clinically decisive and statistically significant improvement in flexibility and sports performance of female rugby players. Based on the findings of this research (chapter 5), a moderate improvement in the flexibility of the hip and hamstring and acceleration phase of sprint performance was found in the players who completed the 12 week yoga intervention.

Since the improvement was only observed in the one flexibility test (straight leg raise test) and the acceleration phase of the sprint (e.g. 5 m distance) in female players, whilst male rugby players were barely able to reach their baseline flexibility after the yoga intervention and had barely improved sprint performance (chapter 4), it is recommended that yoga's effect on flexibility and sprinting ability of rugby players warrants further attention in a larger cohort, with an extended intervention, probably with a larger dose of 3-5 yoga sessions per week in both males and females.

7.4 Effects of yoga on cardiovascular risk factors and health parameters in a healthy adult population.

Based on the learnings from three interventional studies and literature, it was clear that athletes at a young age have a minimal chance of developing any symptoms of cardiovascular disease, thus, it was clear that to investigate the effects of regular yoga practice on cardiovascular health a different population was required. Following that, a cross-sectional study was planned and executed. It has also been suggested that regular yoga practice may improve cardiovascular health (Cramer et al., 2014; Cramer et al., 2018). The fourth study (chapter 6) sought to contribute to this question. Studies have reported that yoga influences the sympathetic and parasympathetic nervous system, blood pressure and heart rate (Cramer et al., 2014). However, the popularity of yoga-related activity in the general population is low when compared to other activities like walking, running and gym workouts. This may be due to the more subjective and poorer quality scientific studies on yoga. Innes et al. (2005) explained various reasons for this scenario, including poorly described research methods, small sample sizes, inadequate statistical analysis, or even lack of control groups. The majority of yoga studies are conducted in India with few in other parts of the world. While a handful of studies have investigated the health benefits of yoga, there is a lack of investigations examining the effects of regular yoga practice to have better cardiovascular health. The novel findings in this portion of the thesis related to the improvement of cardiovascular health (as measured by carotid-femoral pulse wave velocity) in the yoga group compared to the control group. This is the first study investigating the relevance of yoga on cardiovascular health markers by comparing yogis to controls (across all age groups).

Based on the findings (chapter 6), it was clear that regular practice of yoga is associated with lower resting heart rate, systolic blood pressure, and carotid-femoral pulse wave velocity. The majority of these changes were detectable in all yoga participants, however statistical significance was observed only in the highly active and older age groups.

Regular yoga had little association with heart rate variability measures. Nevertheless, regular yoga practice was associated with reduced cardiovascular health markers compared to the controls. Analyses were performed to directly compare the benefits of yoga between groups and yoga was found to be associated with increased overall flexibility and reduced age-related reduction in arterial compliance (i.e. lower PWV).

Overall, the association between yoga and cardiovascular health markers were more difficult to interpret. This is mainly due to the fact that the yoga group was more active in general, and there was no clear evidence that the changes observed in the carotid-femoral pulse wave velocity were due to the yoga practice alone. This suggests that improved carotid-femoral pulse wave velocity is likely to have been the result of various mechanisms including, physiological (Jufri et al., 2015), mechanical (Yamamoto et al., 2004; Yamato et al., 2021), and neural (Gladwell et al., 2005).

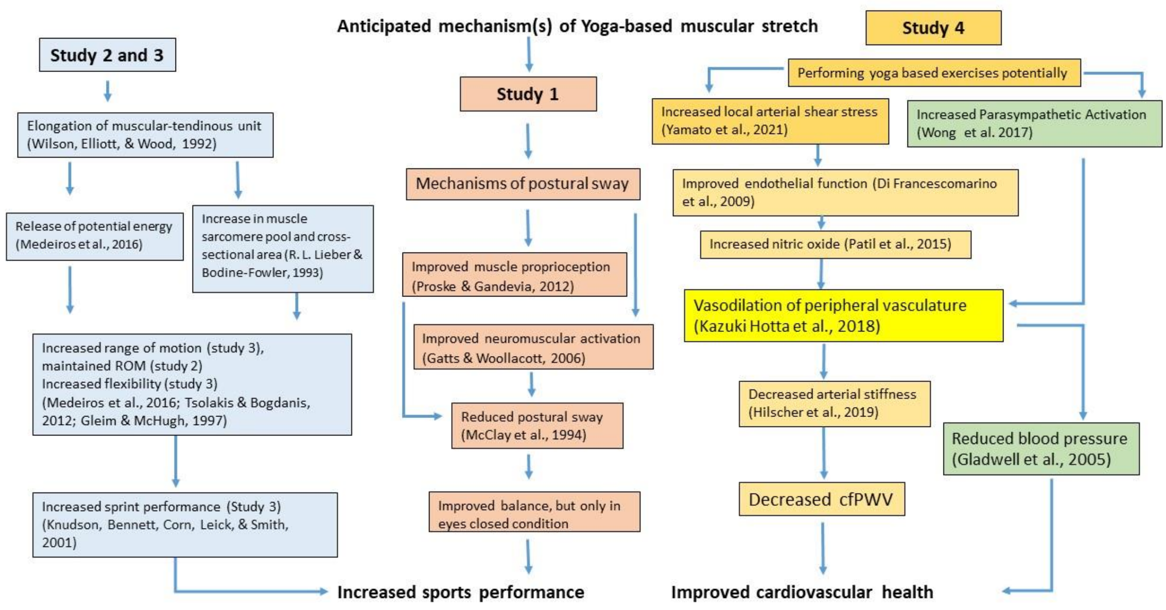
Undoubtedly, physical activity plays a role in improving cardiovascular health (Goenka & Lee, 2017; Hotta et al., 2018), and the increased physical activity in the yoga group compared to the control group was expected. Furthermore, it was also expected the carotid-femoral pulse wave velocity to be lower in all yoga groups, since all groups were more physically active than their control counterparts. Indeed, the carotid-femoral pulse wave velocity was lower across all yoga however, only the young and older age groups reached the statistical significance compared to controls. Such a finding may be due to the increased variance with further segmentation of the participants into relatively smaller subgroups; further analysis is probably required on larger subgroups to substantiate these differences. On the other hand, including yoga as part of a weekly physical activity routine may also contribute to improved arterial health, particularly in older age individuals.

7.5 Conclusion: The effect of yoga on sports performance and health.

The findings presented in this thesis collectively suggest that yoga-based stretching exercise can increase lower-body flexibility, balance, and sprint performance of rugby players, and may also improve arterial compliance in a selected population of older adults. However, it is difficult for athletes to have enough time to devote each week in addition to their already busy weekly training schedules. It is recommended that athletes may use 35 – 45 min of yoga whenever they can, for example, during a light training day. In comparison, an hour of weekly yoga practice may have an additional health benefit for sedentary individuals. Therefore, yoga can be a useful tool for adults to perform the recommended amount of physical activity, particularly as it is a suitable activity for almost everyone regardless of their physical fitness level.

In Figure 11, the proposed mechanisms are outlined for the effects of yoga on rugby players' balance and sprint performance along with the cardiovascular benefits associated with regular yoga practice. Yoga decreases postural sway (Study 1) perhaps by improving the proprioceptor ability of the player. Yoga may do this by improving the sensitivity of the sensory receptor to pick up the information or by improving the motor system delivering the information back to the skeletal muscle or perhaps improving coordination of both systems working together, leading the players to reduce postural sway and improve balance.

Figure 11. Flow chart of anticipated mechanisms for each study.



In studies 2 and 3, yoga either increased or maintained the flexibility of the hamstring muscles in male and female rugby players and thereby increased sprint performance (in females at least). Yoga-based stretching (dynamic) may do this by elongating the muscular-tendinous unit helping muscles to release energy and increasing the ability to generate more power. The yoga interventions used in these studies included dynamic movements requiring the contraction and elongation of the muscle-tendon unit. This shortening and stretching (stretch-shortening cycle) relies on the elastic proprieties of the tendon to enable the release of potential energy, resulting in increased power. A recent review concluded that athletes with a full range of motion may have an advantage over those athletes who don't have the full range of motion, however the authors were also unable to explain the mechanism responsible for the improvements observed (Schoenfeld & Grgic, 2020). The effectiveness of stretching exercises is reported by researchers in terms of increased range of motion (Mchugh & Cosgrave, 2010) in the stretched limb. Kubo, Ikebukuro, and Yata (2019) showed the hypertrophic benefits of full range of motion in the quadriceps muscle complex. Thus, it is possible that the athletes who improved their flexibility or range of motion in the current studies had greater transference of the energy to their joint angle, thereby, increasing the force to improve sprint performance.

Figure 11 also outlines the mechanisms for study 4, as yoga shows evidence of cardiovascular health benefits in the individuals reported in this thesis, which may have been due to several mechanisms. Yoga-based stretching may do this by increasing the local arterial shear stress which may not only cause changes in the endothelial function and blood vessel wall but also may trigger biochemical and biological events such as improved nitric oxide (NO) status. As nitric oxide is a key component to maintain normal vascular tone, improved NO level can lead to better vasodilation of peripheral vasculature. Therefore, it may appear as decreased arterial stiffness or decreased blood pressure resulting in decreased carotid-femoral pulse wave velocity and improved cardiovascular health. As a result of regular yoga practice or increased physical activity, reduction in blood pressure was observed among yoga participants even in the low physical activity group across all age groups.

Stretching may also have a neural effect by altering the autonomic nervous system and its influence on the blood vessel smooth muscles, however this study did not find evidence of this.

The conclusions from the four studies conducted for this thesis supports researcher's clinical experience; yoga was found to be beneficial for rugby players and has health benefits for healthy adults and older adults. Yoga is an easy to perform exercise modality that has multiple health benefits, and it can be practised by anyone. Thus, yoga can be recommended as a suitable exercise for athletes and non-athletes.

7.6 Future recommendations

Recommendation for future studies

1. A larger sample size of players should be utilised in order to determine the effects of yoga on the overall performance of rugby players. It is well understood that a larger sample size provides less variation, and helps to identify the outliers that could skew the data compared to a smaller sample. A large sample size also provides more reliable results with greater precision and power. Furthermore, a sample including players from both genders will provide greater generalisation.

2. A longitudinal study investigating the use of yoga should be conducted in order to see the long-term effects of yoga on athletes. In this thesis, yoga was practised 2 times/week during the season by rugby players and positive changes were observed, however most of them were not significant. A longitudinal study can provide several observations of the subjects studied over a period of time. This would improve the ability of the researcher to detect changes in the subject over time. Furthermore, a longitudinal study may also assist researchers to detect the developments or changes in the characteristics of the subjects studied in both the group and the individuals, which is more likely to help the researcher in understanding if there is cause-and-effect relationships with this activity.

3. Include other analyses, such as hormonal analysis to assist in monitoring the recovery, stress, and other physiological changes in rugby players. Including more measures will increase the power and reduce the variability of highly variable (subjective) measures. It will also allow researchers to estimate the uncertainty and provide a better understanding of the mechanism(s) involved in the improvements observed. The use of other analyses or other markers would provide better insight into the exact effects of yoga on rugby players.

4. Increase the participants' attendance, in a long intervention such as the one used in this thesis, we observed a decline in the participation rate due to various reasons. Future researchers could create a platform or provide guidelines for participants to practice yoga in their own time which would help in reducing participant attrition.

Chapter 8 Health and Safety

During the administration of the yoga intervention (study 1, 2, and 3) correct posture were demonstrated by the yoga teacher to improve participants understanding of posture. Also if participants seemed to be struggling with the postures, they were encouraged verbally and, if required, the participants were also manually assisted (by the teacher) in performing the postures to a satisfactory level. All participants undergoing the test/intervention were monitored closely and the test/intervention was stopped immediately if or when the researcher noticed any contradiction to the test/intervention. If there was any situation with participants (stress-related or medical) that concerned the researcher, this was reported to the Lincoln University student health and support centre, which is an on-campus medical facility, and they were informed regarding the project.

In study 4, due to the nature of this research, and considering the state of the participants, there were some inherent physical and stress-related risks. These risks may include but not limited to, the varying level of discomfort and bruising at the blood extraction site on their fingers. To reduce these risks, the researcher explained to the participants that at any point if they felt discomfort or for any other reason and decided not to provide the blood sample they may withdraw from doing so.

A short explanation of the study and related risks was given to all participants by the researcher related to the process and procedures of the tests. During Central Arterial Pressure Waveform Analysis, the pulse-wave analysis and pulse wave velocity tests required participants to wear a branchial or femoral cuff, these cuffs fit on the upper arm and thigh as high as possible. To avoid any cultural or moral offence, I gave participants the option of attaching these cuffs themselves.

All participants were told that they may withdraw from the study at any point without question or penalty.

Appendix A

Human ethics approval

A.1 Human ethics approval for study 1, 2, and 3

Research Management Office

T 64 3 423 0817
PO Box 85084, Lincoln University
Lincoln 7647, Christchurch
New Zealand
www.lincoln.ac.nz

22 March 2017

Application No: 2017-14

Title: The Effect of a Yoga Intervention on Fitness, Athletic Performance, and Injury.

Applicant: T Raj

The Lincoln University Human Ethics Committee has reviewed the above noted application.
Thank you for your response to the questions which were forwarded to you on the Committee's behalf.

I am satisfied on the Committee's behalf that the issues of concern have been satisfactorily addressed. I am pleased to give final approval to your project.

Please note that this approval is valid for three years from today's date at which time you will need to reapply for renewal.

Once your field work has finished can you please advise the Human Ethics Secretary, Alison Hind, and confirm that you have complied with the terms of the ethical approval.

May I, on behalf of the Committee, wish you success in your research.

Yours sincerely

Grant Tavinor
Chair, Human Ethics Committee

PLEASE NOTE: The Human Ethics Committee has an audit process in place for applications. Please see 7.3 of the Human Ethics Committee Operating Procedures (ACHE) in the Lincoln University Policies and Procedures Manual for more information.

A.2 Human ethics approval for study 4

Research Management Office

T 64 3 423 0817
PO Box 85084, Lincoln University
Lincoln 7647, Christchurch
New Zealand
www.lincoln.ac.nz

23 November 2018

Application No: 2018- 42

Title: Effects of regular yoga on cardiovascular indices.

Applicant: T Raj

The Lincoln University Human Ethics Committee has reviewed the above noted application. Thank you for your response to the questions which were forwarded to you on the Committee's behalf.

I am satisfied on the Committee's behalf that the issues of concern have been satisfactorily addressed. I am pleased to give final approval to your project.

Please note that this approval is valid for three years from today's date at which time you will need to reapply for renewal.

Once your field work has finished can you please advise the Human Ethics Secretary, Alison Hind, and confirm that you have complied with the terms of the ethical approval.

May I, on behalf of the Committee, wish you success in your research.

Yours sincerely

Grant Tavinor
Chair, Human Ethics Committee

PLEASE NOTE: The Human Ethics Committee has an audit process in place for applications. Please see 7.3 of the Human Ethics Committee Operating Procedures (ACHE) in the Lincoln University Policies and Procedures Manual for more information.

A.3 Advertisement for recruitment of participants for study 1,2 and 3

RUGBY PLAYERS WANTED FOR A RESEARCH STUDY

Are you interested in getting fitter for your sport?
Would you like to improve your flexibility?
Do you want to learn more about improving your performance?

If you have answered yes to any of these questions please email or phone for more information about getting involved in an upcoming rugby study at Lincoln University.

Tilak Raj (PhD student researcher)
Department of Tourism, sports, and society.
Email : TilakRaj.TilakRaj@lincolnuni.ac.nz
Phone : 0274262195

Lincoln University
Te Whare Wānaka o Aoraki
AOTEAROA • NEW ZEALAND

New Zealand's specialist land-based university

A.4 Advertisement for recruitment of participants for study 4

LINCOLN UNIVERSITY
TE WHARE WĀNAKA O AORAKI

Lincoln University
PO Box 85084, Lincoln 7647
Christchurch, New Zealand
0800 10 60 10
www.lincoln.ac.nz

Would you like to know, how daily activities affect the health of your heart and blood vessels?

GET INVOLVED IN ONE OF OUR LATEST RESEARCH STUDIES.

What you will receive.

1. Free blood pressure test
2. Free blood glucose test
3. Free cholesterol test
4. Free BMI testing
5. You will get to know the age of your arteries

To participate in the study (in yoga group)

1. Be above 18 years of age
2. Practicing yoga for 2-3 times a week for more than 3 months
3. Do not have any heart condition
4. Currently not on any medication

To participate in the study (in non-yoga group)

1. Be above 18 years of age
2. Do not have any heart condition
3. Currently not on any medication

If you are interested being a participant in the study,

Please contact at:

TilakRaj.TilakRaj@lincolnuni.ac.nz or 0274262195

A.5 Research information sheet for the participants of study 1, 2, and 3

Lincoln University

Faculty of Environment Society and Design, Department of Tourism, Sport and Society

Research Information Sheet

I would like to invite you to participate in a PhD. project entitled “The Effect of a Yoga Intervention on Fitness, Athletic Performance, and Injury”.

This project aims to examine the effects of yoga on fitness, athletic performance and injury of rugby players. This project will involve learning and practice of yoga postures (involves various static and dynamic body position) alongside regular rugby practice.

Your participation in this PhD project will involve various physical fitness and sports specific tests such as muscular strength, balance, muscular endurance, flexibility, static squat jump, cardiorespiratory fitness, body composition, speed test, repeated sprint ability, agility, and two questionnaires (Borg’s rate of perceived exertion, and Sports-Related Anxiety Test). These tests will occur at the start of the season and then again half way through the season and at the end of the season and will take approximately 30-40 min to complete.

During the season you will be required to undertake 2 yoga sessions per week each lasting approximately 50 min. The sessions will be scheduled in a time that avoids rugby and educational commitments. The yoga sessions will contain stretches and movements that are required during a game of rugby. In total, approximately 52 hours will be required from you (including the test times and the yoga sessions) over the entire season.

If you would like to take part in the study and have any queries or concerns about your participation in the project, please contact **Tilak Raj** in the first instance by **15th April 2017**. I would be happy to discuss any concern or comments you have about your participation in the project.

The results of the project may be presented in conferences and published in journal articles. Only aggregated data will be presented in any publications and no information will be reported in a way that might identify individuals. You may be assured of your anonymity in this investigation: the identity of any participant will not be made public or made known to any person other than the researcher, his supervisor, or the Lincoln University Human Ethics Committee. The latter may occur only in the event of an audit. To ensure anonymity, individual survey data will be seen only by the researcher (Tilak Raj) and his supervisors and will be stored in a locked cabinet separate from official documents. Only aggregated data will be presented in any publications and no information will be reported in a way that might identify individuals.

Your participation in this research is voluntary. Your choice to participate or not participate will have no bearing on any current or future aspect of your sports career. You may decline to answer any questions. You may withdraw from the project, including withdrawing any information you have provided, up to **31st October 2017** by contacting **Tilak Raj** or **Dr Michael Hamlin** through the contact details below.

Researcher: Tilak Raj, Faculty of Environment society and Design,
Department of Tourism, Sport and Society,
TilakRaj.TilakRaj@lincolnuni.ac.nz
Ph.: 03-423-0440

Supervisor: Dr Michael Hamlin, Faculty of Environment society and Design,
Department of Tourism, Sport and Society,
Michael.Hamlin@lincoln.ac.nz
Ph.: 03-423-0489

A.6 Research information sheet for the participants of study 4

Lincoln University

Faculty of Environment Society and Design, Department of Tourism, Sport and Society

Research Information Sheet

I would like to invite you to participate in a PhD project entitled "Effect of regular yoga on cardiovascular health indices".

This study is part of a PhD project currently being undertaken at Lincoln University. This project will involve testing the effects of regular yoga practice on cardiovascular risk factors and health parameters.

Your participation in this PhD project will involve various tests such as flexibility, heart rate measures, body fat percentage, body mass index (BMI), waist to hip ratio, cerebral oxygenation and cardiovascular disease risk factors such as blood pressure, arterial stiffness, blood glucose, lipid profile, and two questionnaires (International physical activity questionnaire (IPAQ) and measures of perceived stress scale (PSS)) will be monitored and collected in 2018-19. The lipid and glucose test requires a small finger prick to enable me to take a small drop of blood for the test. This finger prick may cause a small sharp pain but no long-lasting effects should occur. These tests will occur once and will take approximately 1 hour to complete.

If you agree to take part in this study you will be selected into one of the following groups (a yoga group for participants that complete 2-3 sessions of yoga per week over the last 3 months, or a control group that has not completed any regular (2-3 times per week) yoga or stretching exercise). The testing will be scheduled at a time that avoids your work and family commitments. In total, approximately 1hour will be required from you (including the test times).

If you would like to take part in the study or have any queries or concerns about your participation in the project, please contact **Tilak Raj** in the first instance by **31st July 2019**. I would be happy to discuss any concern or comments you have about your participation in the project.

The results of the project may be presented in conferences and published in journal articles. Only aggregated data will be presented in any publications and no information will be reported in a way that might identify individuals. You may be assured of your anonymity in this investigation: the identity of any participant will not be made public or made known to any person other than the researcher, his supervisor, or the Lincoln University Human Ethics Committee. The latter may occur only in the event of an audit. To ensure anonymity, individual survey data will be seen only by the researcher (Tilak Raj) and his supervisors and will be stored in a locked cabinet separate from official documents.

Your participation in this research is voluntary. You may decline to answer any questions. You may withdraw from the project, including withdrawing any information you have provided at any point, up to **31st October 2019** by contacting Tilak Raj or Dr Michael Hamlin through the contact details below.

Researcher: Tilak Raj, Faculty of Environment society and Design,
Department of Tourism, Sport and Society,
TilakRaj.TilakRaj@lincolnuni.ac.nz
Ph.: 03-423-0440, Mob - 0274262195

Supervisor: Dr Michael Hamlin, Faculty of Environment society and Design,
Department of Tourism, Sport and Society,
Michael.Hamlin@lincoln.ac.nz
Ph.: 03-423-0489

A.7 Questionnaires used for the data collection (study 4)

Name of Project: “Effect of regular yoga on cardiovascular health indices”.

I have read and understood the description of the above-named project. On this basis, I agree to participate in the project, and I consent to the publication of the results of the project with the understanding that anonymity will be preserved. I also understand that I may withdraw from the project, including withdrawal of any information I have provided, up to **31st October 2019**.

This is to be completed before your Testing. All information will be kept confidential. This information will be used for the evaluation of your health. The form is extensive, but please try to make it as accurate and complete as possible. Please take your time and complete it carefully and thoroughly, and then review it to be certain you have not left anything out.

If you have questions or concerns, I will help you with those after this form is completed. I understand that some parts of the form will be unclear to you. Do your best to complete the form. Your questions will be thoroughly addressed afterwards. It might be helpful for you to keep a written list of questions or concerns as you complete the medical history form.

Name:

Signed:

Date:

A.8 Medical questionnaire used for the data collection (study 4)

MEDICAL HISTORY QUESTIONNAIRE

Education:

☐ Grade School ☐ Jr. High School ☐ High School ☐ College (2-4 years)
☐Graduate School ☐ Degree _______________

Occupation:

Present Medical History

Check those questions to which you answer yes (leave the others blank).

- ☐ Has a doctor ever said your blood pressure was too high?
- ☐ Do you ever have pain in your chest or heart?
- ☐ Has a doctor ever said that you have or have had heart trouble, an abnormal electrocardiogram (ECG or EKG), heart attack or coronary?
- ☐ Has a doctor ever told you your cholesterol level was high?
- ☐ Has a doctor ever told you that you have an abdominal aortic aneurysm?
- ☐ Has a doctor ever told you that you have critical aortic stenosis?

Do you now have or have you recently experienced:

- ☐ Increased anxiety or depression?
- ☐ Problems with recurrent fatigue, trouble sleeping or increased irritability?
- ☐ Significant vision or hearing problems?
- ☐ Glaucoma or increased pressure in the eyes?
- ☐ Significant unexplained weight loss?
- ☐ A deep vein thrombosis (blood clot)?

Women only answer the following.

- ☐ Are you having Menstruation now?

Men and women answer the following:

List any prescription medications you are now taking: ____

____

List any self-prescribed medications, dietary supplements, or vitamins you are now taking: ___________

____

Date of last complete physical examination: ____

Past Medical History

Check those questions to which your answer is yes (leave others blank).

- ☐ Heart attack if so, how many years ago? ________
- ☐ Diseases of the arteries
- ☐ Varicose veins
- ☐ Diabetes or abnormal blood-sugar tests
- ☐ Epilepsy or seizures
- ☐ Stroke
- ☐ Nervous or emotional problems
- ☐ Pneumonia
- ☐ Bronchitis
- ☐ Asthma
- ☐ Abnormal chest X-ray
- ☐ Other lung disease

Family History

Have you or your blood relatives had any of the following (include grandparents, aunts and uncles, but exclude cousins, relatives by marriage and half-relatives)?

Check those to which the answer is yes (leave other blank).

- ☐ Heart attacks under age 50
- ☐ Strokes under age 50
- ☐ High blood pressure
- ☐ Elevated cholesterol
- ☐ Diabetes
- ☐ Asthma or hay fever
- ☐ Congenital heart disease (existing at birth but not hereditary)
- ☐ Heart operations
- ☐ Glaucoma
- ☐ Obesity (20 or more pounds overweight)
- ☐ Leukemia or cancer under age 60

Smoking

Have you ever smoked?

☐ Yes ☐ No - **(if no, skip to the diet section)**

How often do you smoke?

Regularly ☐Yes ☐No, Sometimes ☐Yes ☐No

If you have stopped smoking, when was it? ____

Diet

What do you consider a good weight for yourself? ____

What is the most you have ever weighed (including when pregnant)? ____________________________

Number of meals you usually eat per day: ____

Number of times per week you usually eat the following:

Beef ____________ Fish ____________ Desserts____________

Pork ____________ Fowl ____________ Fried Foods__________

Number of servings (cups, glasses, or containers) per week you usually consume of:

Homogenized (whole) milk __________ Buttermilk __________________ Skim (nonfat) milk ____

2% (low-fat) milk __________________ 1% (low-fat) milk ____________ Coffee ______________

Tea (iced or not) ___________________ Regular or diet sodas __________ Glasses of water ______

Do you usually use oil or margarine in place of high cholesterol shortening or butter?

☐ Yes ☐ No

Do you usually abstain from extra sugar usage?

☐ Yes ☐ No

Do you usually add salt at the table?

☐ Yes ☐ No

Do you eat differently on weekends as compared to weekdays?

☐ Yes ☐ No

Drinking

Do you ever drink alcoholic beverages?

☐ Yes ☐ No

If yes, what is your approximate intake of these beverages?

Beer:

☐ None ☐ Occasional ☐ Often If often, _____ per week

Wine:

☐ None ☐ Occasional ☐ Often If often, _____ per week

Hard Liquor:

☐ None ☐ Occasional ☐ Often If often, _____ per week

At any time in the past, were you a drinker?

☐ Yes ☐ No, If you have stopped drinking, when was it? ______________

A.9 Perceived stress scale used for the data collection (study 4)

INSTRUCTIONS:

The questions in this scale ask you about your feelings and thoughts during THE LAST MONTH. In each case, you will be asked to indicate your response by placing an "X" over the circle representing HOW OFTEN you felt or thought a certain way. Although some of the questions are similar, there are differences between them, and you should treat each one as a separate question. The best approach is to answer fairly quickly. That is, don't try to count up the number of times you felt a particular way, but rather indicate the alternative that seems like a reasonable estimate.

	Never	Almost Never	Sometimes	Fairly Often	Very Often
	0	1	2	3	4
1. In the last month, how often have you been upset because of something that happened unexpectedly?	O	O	O	O	O
2. In the last month, how often have you felt that you were unable to control the important things in your life?	O	O	O	O	O
3. In the last month, how often have you felt nervous and "stressed"?	O	O	O	O	O
4. In the last month, how often have you dealt successfully with day to day problems and annoyances?	O	O	O	O	O
5. In the last month, how often have you felt that you were effectively coping with important changes that were occurring in your life?	O	O	O	O	O
6. In the last month, how often have you felt confident about your ability to handle your personal problems?	O	O	O	O	O
7. In the last month, how often have you felt that things were going your way?	O	O	O	O	O
8. In the last month, how often have you found that you could not cope with all the things that you had to do?	O	O	O	O	O
9. In the last month, how often have you been able to control irritations in your life?	O	O	O	O	O
10. In the last month, how often have you felt that you were on top of things?	O	O	O	O	O

PSS-14

	Never	Almost Never	Sometimes	Fairly Often	Very Often
	0	1	2	3	4
11. In the last month, how often have you been angered because of things that happened that were outside of your control?	○	○	○	○	○
12. In the last month, how often have you found yourself thinking about things that you have to accomplish?	○	○	○	○	○
13. In the last month, how often have you been able to control the way you spend your time?	○	○	○	○	○
14. In the last month, how often have you felt difficulties were piling up so high that you could not overcome them?	○	○	○	○	○

A.10 International physical activity questionnaires used for the collection of weekly physical activity (study4)

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE (August 2002)

SHORT LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH YOUNG AND MIDDLE-AGED ADULTS (15-69 years)

The International Physical Activity Questionnaires (IPAQ) comprises a set of 4 questionnaires. Long (5 activity domains asked independently) and short (4 generic items) versions for use by either telephone or self-administered methods are available. The purpose of the questionnaires is to provide common instruments that can be used to obtain internationally comparable data on health–related physical activity.

Background on IPAQ

The development of an international measure for physical activity commenced in Geneva in 1998 and was followed by extensive reliability and validity testing undertaken across 12 countries (14 sites) during 2000. The final results suggest that these measures have acceptable measurement properties for use in many settings and in different languages, and are suitable for national population-based prevalence studies of participation in physical activity.

Using IPAQ

Use of the IPAQ instruments for monitoring and research purposes is encouraged. It is recommended that no changes be made to the order or wording of the questions as this will affect the psychometric properties of the instruments.

Translation from English and Cultural Adaptation

Translation from English is supported to facilitate worldwide use of IPAQ. Information on the availability of IPAQ in different languages can be obtained at www.ipaq.ki.se. If a new translation is undertaken we highly recommend using the prescribed back translation methods available on the IPAQ website. If possible please consider making your translated version of IPAQ available to others by contributing it to the IPAQ website. Further details on translation and cultural adaptation can be downloaded from the website.

Further Developments of IPAQ

International collaboration on IPAQ is on-going and an ***International Physical Activity Prevalence Study*** is in progress. For further information see the IPAQ website.

More Information

More detailed information on the IPAQ process and the research methods used in the development of IPAQ instruments is available at www.ipaq.ki.se and Booth, M.L. (2000). *Assessment of Physical Activity: An International Perspective*. Research Quarterly for Exercise and Sport, 71 (2): s114-20. Other scientific publications and presentations on the use of IPAQ are summarized on the website.

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

1. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

   _____ **days per week**

   ☐ No vigorous physical activities → ***Skip to question 3***

2. How much time did you usually spend doing **vigorous** physical activities on one of those days?

   _____ **hours per day**

   _____ **minutes per day**

   ☐ Don't know/Not sure

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

3. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

   _____ **days per week**

   ☐ No moderate physical activities → ***Skip to question 5***

SHORT LAST 7 DAYS SELF-ADMINISTERED version of the IPAQ. Revised August 2002.

4. How much time did you usually spend doing **moderate** physical activities on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you have done solely for recreation, sport, exercise, or leisure.

5. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

_____ **days per week**

☐ No walking → ***Skip to question 7***

6. How much time did you usually spend **walking** on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the **last 7 days**, how much time did you spend **sitting** on a **week day**?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

This is the end of the questionnaire, thank you for participating.

SHORT LAST 7 DAYS SELF-ADMINISTERED version of the IPAQ. Revised August 2002.

A.11 Overall data collection sheet (study 4)

Data Collection sheet

Testing Date	
Participant ID	
DOB	
Age	
Sex	
Ethnicity	
How many times in a week you practice yoga?	1 – 2 – 3 or more
Polar watch attached?	Yes/No
Blood Pressure	
Total Cholesterol mg/dL	<240 - >240
Blood Glucose mg/dL	72-108 fasted, <140 not fasted
PWA	
Brachial Systolic BP mmHg	<120 120-139 >139
Brachial Diastolic BP mmHg	<80 80-89 >89
Aortic Systolic BP mmHg	<120 120-139 >139
Aortic Diastolic BP mmHg	<80 80-89 >89
PP	
AP	
AIx	
Artery Reference Age	<age
Carotid to Cuff distance	
Femoral to Cuff distance	
Resting Heart Rate (bpm)	60-75 adults
PWV Speed (m/s)	<12
PTT	
Perceived Stress Scale	
Flexibility Score	
Total Body Fat	
PBF	
SMM	
Height	
Weight	
WHR	
BMI	

Appendix B

Published work

B.1 Study 1 Published in a peer-reviewed journal

ORIGINAL ARTICLE

Arch AHS

Archives of Allied Health Sciences 2020; 32(3): 13-21.

Effects of a 12-week yoga intervention on postural sway in rugby union players

Tilak Raj[1*], Catherine Elliot[1], Michael J. Hamlin[1]

[1] Department of Tourism, Sport & Society, Lincoln University, New Zealand.

KEYWORDS

Exercise;
Proprioception;
Sports performance;
Balance training.

ABSTRACT

In an attempt to reduce the risk of injury that accompanies poor balance, many strength and conditioning coaches and trainers incorporate balance and postural control training into players' training regimes. However, relatively few balance interventions involve yoga. Therefore, the purpose of this study was to evaluate the effect of a modified yoga programme on postural sway in rugby union players. Twenty-nine male rugby union players, (19 ± 1.3 years old, mean ± SD) were randomly assigned to two groups: a yoga group (YG, n =15), which practiced yoga for one hour, two times a week alongside their regular rugby training, and a control group (CG, n = 14), which only participated in their standard rugby training. Postural sway was measured during various 30s balance activities at baseline (pre-season) and at the end of the 12-week playing season (post-season) on a force platform. The yoga group showed a significantly reduced sway signal in the 2-legged eyes closed balance test in the antero-posterior (-109.7% ± 82.9 mean ± 95% CI, *p*-value < 0.005) and medial-lateral (-115.5% ± 92.1, p-value < 0.005) directions. However, no significant between-group change was found in the 1-legged eyes closed or 1 or 2-legged eyes open balance tests. The results suggest that practising yoga may reduce postural sway in specific directions which may improve balance in rugby union players.

* **Corresponding author:** Tilak Raj, Faculty of Environment Society and Design, Department of Tourism, Sport & Society, Lincoln University, New Zealand. P O Box 85084, Lincoln 7647, Canterbury, New Zealand. Tel: +64 274262195
E-mail: TilakRaj.TilakRaj@lincolnuni.ac.nz
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Introduction

Rugby union (hereinafter referred to as "rugby") is a field-based contact sport with a growing player base of approximately 9.1 million players registered worldwide, making it one of the most popular sports in England, Ireland, Australia, and New Zealand(1). Rugby players are typically strong and engage in many bouts of high-intensity activity(2) including running, jumping, kicking, and other quick, agile movements(2). The fast pace and physical contact in rugby makes it essential that players are able to quickly control posture and return to a steady position when exposed to balance perturbations(3). In addition, rugby players need to maintain a stable posture for the safe execution of efficient and effective movements(4, 5). Therefore, better postural stability, or improved balance, plays a vital role in rugby players' performance.

Rugby is dynamic in nature, and rugby players are required to actively balance their body weight depending on the game situation(2). As part of the game, rugby players tackle opposing players to gain possession of the ball or are occasionally required to kick the ball while running, which requires good balance, sometimes on one leg as well as in compromising positions(3). To control posture, a player must maintain control of his centre of gravity by remaining as close to the centre as possible using hip and ankle balance strategies(2,6). If the change in the centre of gravity is large due to either inappropriate neuromuscular strategies selected by the player or an impaired ability to use the sensory feedback efficiently, the player may develop impaired balance and increased postural instability(5), which have been associated with an increased risk of injury(7).

Postural sway is a method of observing the sway of a player's centre of pressure (COP) displacement and body weight distribution and can be used as a measure of balance(8,9). To reduce postural sway, an efficient sensory-muscular feedback response is required(8,10) and any delay or inattention to this response may increase postural sway, particularly in the anterior -posterior and medial-lateral planes, which may result in undesired movement patterns, which could possibly affect a player's performance(10,11). Hatha yoga, the yoga used in this study, is an ancient Indian system involving various static and dynamic stretching positions, as well as breathing, and relaxation techniques. It is progressive in nature and low-cost, only requiring a trained yoga teacher and no specialised equipment. While yoga has been shown to improve balance in athletes(12,13) and older adults(14,15) little research has addressed the contribution of yoga towards enhancing the balance of rugby union players. This study is designed to determine the effects of a 12-week yoga intervention on single- and double-legged postural sway of male rugby union players.

Materials and methods

A yoga intervention was exclusively designed for rugby players and delivered by a yoga instructor (registered exercise professional, New Zealand). The number of participants required for the study was calculated using a spreadsheet with the smallest worthwhile change in performance being 1.0% and the typical error or within-subject SD in similar tests of 0.7%(16). This calculation estimated we needed 7 participants in each group in a controlled trial research design. All participants were in the same yoga class, and all sessions were completed in a large open fitness room. The centre of pressure (COP) is evaluated by collecting the raw data on the magnitude of the force signals applied from the player's body through his feet in the anterior-posterior, and the medial-lateral, directions. COP is also derived from the data collected in the vertical direction on the force platform. To assess postural sway, the movement of the COP is computed by calculating the pressure applied in the direction of the action and then the system measures the associated pressure underneath the foot of the player on the platform. The mean velocity of the raw signal received in anterior-posterior, medial-lateral, and vertical directions and a combination of all were used to assess postural sway using COP(17). During the intervention, players spent the first 10 min performing a set of 12 dynamic stretching postures used as a warm-up (sun-salutation sequence), an easy to follow routine to standardise the practice throughout the study. Players then performed 17 sets of 30 s stretches focussing on quadriceps, hamstring, calves in five different postures, three postures with 13 sets of 20 s stretches focusing on hamstring, 17 sets of 10 s stretches focussing on gluteal and lower back area in eight postures, 10 sets of 15 s stretches focussing on shoulders, upper-back, and abdominal area in six postures, 4 sets of 15 s stretching focussing on middle back in four posture, and 4 sets of 20 s stretching focussing on hip abductor and hip adductors in two postures. The postures performed during the intervention are typically a combination of joints and muscles.

Participants

The inclusion criteria for the study included currently playing rugby at club level, having no past experience of yoga, and having no current or previous injury which may affect their participation in the study. Twenty-nine male club-level rugby union players (19 ± 1.3 years, mean ± SD) (Table 1) volunteered to participate in the study, and were divided into two groups: a yoga group (YG n =14), which practiced yoga for one hour, two times a week in addition to normal rugby training and a control group (CG n = 15), that completed their normal rugby training without yoga. During the study, players were asked to refrain from physical activities that might affect balance outside of those provided by their strength and conditioning coach. All players completed a medical questionnaire (Physical Activity Readiness Questionnaire) and reported no contraindications to engaging in maximal exercise. All players were also informed about the possible risks of volunteering for this study and provided written informed consent prior to the study. Following the Declaration of Helsinki, this research was approved by the institutional Human Ethics Committee.

Table1 Baseline characteristics of the players

Characteristics	Yoga Group (*n* = 15)	Control Group (*n* = 14)
Age (y)	19 ± 1.3	19 ± 2.0
Height (cm)	181.3 ± 8.4	182.7 ± 4.2
Weight (kg)	88.9 ± 18.7	85.5 ± 9.8
BMI (kg/m^2)	26.9 ± 4.8	25.6 ± 2.8

Note: Data are mean ± SD.

Yoga intervention

A registered yoga instructor led the 60 min yoga intervention classes twice a week for 12 weeks, with the intervention starting at the beginning of the rugby season. Each yoga session consisted of a warm-up of 10 min (Surya-namaskar a dynamic stretching sequence of postures), followed by 35 min of yoga postures (10 min standing, 10 min sitting, and 15 min of supine and prone postures and a mix of static and dynamic postures), and 10 min relaxation in the final resting position (lying in supine position without any stretching exercise). A total of 5 min was allocated for the transition between the yoga postures. The sessions consisted of 32 yoga postures (including standing, sitting, forward bending, backward bending, spinal twist, core engagement and body inversion), targeting the major muscle groups of the body (e.g., gastrocnemius, hip flexors, hip extensors, abdominals, and trapezius). Basic breathing and relaxation techniques were taught in the first 2 weeks of the intervention after the initial session players practised these two techniques for the remaining six weeks. The yoga postures were modified to improve the range of motion, and promote the progression of difficulty and intensity with the support of yoga props (such as blocks, straps, or ropes), so movements were performed as accurately as possible without inducing pain beyond that experienced with stretching.

Postural sway measurement

Data were collected over a 30 s period with a sampling frequency of 100 Hz in the morning between 0900-1200 using a force platform (Bertec Corp, Columbus, OH) which amplifies, filters, and digitises the raw signals from the strain gauge amplifiers inside the force plate. The resulting output is a six-channel 16-bit digital signal containing the forces and moments in the x, y, and z axes. The digital signals were subsequently converted via an external analogue amplifier (AM6501, Bertec Corporation). The initial centre of pressure signals was calculated with respect to the centre of the force-plate before normalization. Data were collected on two occasions (baseline and after the 12-week intervention). The players were instructed to stand normally on the force platform barefoot, with feet in the centre of a marked area and their arms hanging by their side. While standing on the force platform, players were asked to concentrate on a fixed spot on the wall in front of them and to maintain their balance as much as possible (or to maintain balance for as long as possible in the eyes closed test). The data was collected once players said they were comfortable with their standing position. The leg(s) was/were tested (right, left, and 2-legged) and the order of each task was randomly allocated. During testing, the players were asked to complete the following tasks: 1-legged stance with eyes open (right and left leg), a 2-legged stance with eyes open and eyes closed. Each position was held for 30 s and players were given a 1-min rest between each task, where they chose to either sit or stand and were allowed to drink water. The measurement took approximately 5-6 min for each player to complete. All players were required not to perform any strenuous exercise for 24 hours prior to testing. The testing was completed at the same time of day under similar climatic conditions for both testing days.

Statistical analysis

Data were collected from the force platform which included movement in the: antero-posterior, medial-lateral, and vertical directions, and also included centre of pressure in anterior-posterior and medial-lateral directions, and exported to Microsoft excel and analysed using R studio (2019) (Boston, MA, USA). To analyse the raw data, a protocol described by Önell[18] was employed. Firstly, the players' body mass was normalised with the signal collected. To remove the body oscillations due to the heartbeat, the signal was sent through a 4th-order Butterworth high pass filter with a cut-off frequency of 0.1 Hz. The signal was also low pass filtered with a cut-off frequency of 15 Hz to reduce measurement noise to remove slow drifts in the signal which are not directly associated with spontaneous sway. The standard deviation of the mean of each 30 s signal was used as an indicator of postural sway variability.

A total of 9 measures were recorded, since the data were normalised with mass of the player, mass signal was removed from the analysis and the following measures were used for the final analysis. The standard deviation (SD) of the antero-posterior, medial-lateral, and vertical, directions and centre of pressure in antero-posterior and medial-lateral directions. The data presented in the table 2 are the mean and the standard deviation of each task within the group. The between-group percentage change from baseline to post-intervention was then calculated. Changes within and between groups were estimated using a mixed modelling procedure (Proc Mixed) in the Statistical Analysis System (Version 9.3, SAS Institute, Cary, North Carolina, USA) with an alpha level of 0.05.

Results

The average yoga session attendance rate was 21 sessions (75%), with some players attending all 24 sessions and some attending only 16 sessions (60%), however no players missed two consecutive sessions. Total time spent on stretches amounted to 35 ± 2 min (mean ± SD) at each yoga session. Players spent approximately 25 ± 3 min performing dynamic stretching, which included 10 min of sun-salutation practice, and around 12 - 15 min in both dynamic and static stretching postures. Players were also required to complete 10 min of a mindful relaxation or mental recovery (savasana) at the end of each session.

Compared to the control group, the yoga group that incorporated 12 weeks of yoga into their rugby training routines had a significantly reduced postural sway in the 2-legged eyes closed antero-posterior -109.7% ± 82.9 and medial-lateral -115.5% ± 92.1 (mean ± 95% CI, p-value < 0.005) directions (Table 2). The yoga group demonstrated, in most cases, non-significant decreases in postural sway in a number of balance markers in all stance conditions (right leg eyes open, left leg eyes open, both legs eyes closed, both legs eyes open), when compared to the control group (Table 2).

Table 2 Data of balance tests before and after 12 weeks of yoga in the yoga and control groups and the between group differences

Balance markers	Control group		Yoga group		Pre-post between group differences (%) Mean ± 95%CI
	Baseline	12-week Post	Baseline	12-week Post	
One-legged Right Leg Eyes Open					
Medio-lateral	0.04 ± 0.02	0.04 ± 0.01	0.03 ± 0.02	0.02 ± 0.01	-84.0% ± 155.4
Antero-posterior	0.03 ± 0.01	0.04 ± 0.01	0.03 ± 0.01	0.03 ± 0.03	-69.1% ± 143.6
Vertical	0.05 ± 0.03	0.08 ± 0.02	0.05 ± 0.03	0.05 ± 0.04	-133.4% ± 289.2
Medio-lateral COP	0.00 ± 0.01	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	15.4% ± 246.9
Antero-posterior COP	0.00 ± 0.01	0.00 ± 0.00	0.00 ± 0.01	0.00 ± 0.00	-48.2% ± 269.6
One-legged Left Leg Eyes Open					
Medio-lateral	0.04 ± 0.02	0.05 ± 0.02	0.03 ± 0.02	0.03 ± 0.01	-59.5% ± 90.2
Antero-posterior	0.03 ± 0.01	0.06 ± 0.02	0.03 ± 0.01	0.03 ± 0.01	-39.2% ± 68.3
Vertical	0.05 ± 0.03	0.11 ± 0.05	0.05 ± 0.03	0.05 ± 0.02	-101.7% ± 277.7
Medio-lateral COP	0.02 ± 0.05	0.00 ± 0.00	0.01 ± 0.02	0.00 ± 0.00	83.1% ± 274.1
Antero-posterior COP	0.01 ± 0.03	0.00 ± 0.00	0.01 ± 0.02	0.00 ± 0.00	-14.5% ± 273.8
Two-legged Eyes Open					
Medio-lateral	0.01 ± 0.01	0.03 ± 0.01	0.01 ± 0.01	0.02 ± 0.01	-64.2% ± 90.0
Antero-posterior	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	-62.7% ± 80.5
Vertical	0.01 ± 0.01	0.04 ± 0.01	0.01 ± 0.00	0.01 ± 0.00	-141.9% ± 221.5
Medio-lateral COP	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	-38.7% ± 58.4
Antero-posterior COP	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	-45.8% ± 97.1
Two-legged Eyes Closed					
Medio-lateral	0.03 ± 0.03	0.02 ± 0.00	0.02 ± 0.01	0.01 ± 0.00	-115.5% ± 92.1*
Antero-posterior	0.01 ± 0.00	0.02 ± 0.00	0.00 ± 0.01	0.00 ± 0.01	-109.7% ± 82.9*
Vertical	0.01 ± 0.00	0.05 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	-175.7% ± 197.7
Medio-lateral COP	0.01 ± 0.02	0.00 ± 0.00	0.00 ± 0.01	0.00 ± 0.00	-33.7% ± 242.1
Antero-posterior COP	0.00 ± 0.01	0.00 ± 0.00	0.00 ± 0.01	0.00 ± 0.00	-113.4% ± 281.4

Note: Data are mean ± SD of each group and the difference between groups given as the percent mean difference ± 95% confidence interval. *Statistically significant between groups (p-value < 0.05). COP, Centre of pressure.

Discussion

Findings of this study suggest that 12 weeks of practising a standard yoga routine twice weekly for one hour in addition to normal rugby training can maintain and, in some cases, improve postural sway in male rugby union players. The improvement was particularly prevalent in the antero-posterior and medial-lateral directions in the 2-legged eyes closed stance. Although there were no significant differences in the other sway characteristics of either 1-legged or 2-legged stances, the yoga group mostly showed improvements in all balance measures, when compared to the control group. The results of this study supports previous findings indicating that regular yoga practice may decrease postural sway and improve balance for athletes[12,13] and other individuals[19-21]. The yoga group also had the lowest signal magnitude in the vertical direction in all standing positions, suggesting a more stable stance than the control group. This reflects reduced underfoot activity and improved perceptual-motor skill, allowing the player to maintain a steady position[22].

In this study, the yoga intervention integrated a series of mind-body exercises together with breathing, alignment, relaxation, flexibility and stretching as used by previous researchers[23-26]. Practicing mind-body exercises can result in significantly improved balance[23-25, 27]. For example, Gatts and Woollacott[25] reported that Tai-chi, a routine similar to yoga, improved neuromuscular activation in older adults when compared to a control group that did not practice Tai-chi.

There is mounting evidence that an efficient musculo-skeletal system improves muscle proprioception which may result in improved balance[4,5,23,24,28]. It has been reported that yoga helps individuals to improve their balance, enhances feedback from the muscles and tendons surrounding the joints[29], and reduces underfoot activity[22]. A rugby player uses the lower body extensively to run at various speeds[30], and uses a hip-ankle strategy to change the direction swiftly[2]. Thus, the improved balance of players in the yoga group may help them in the directional play required in rugby.

Consequently by practicing yoga postures included in the current study, players may have upregulated strategies to maintain balance[21,31], thereby leading to an efficient musculo-skeletal system which improved muscle proprioception and resulted in less sway and possibly better balance[4,5,23,24,28]. Efficient functional movement requires the intergration of sensory feedback systems to maintain stability and balance. These systems are particularly important in tasks that occur at high speed and when directional change is involved[32]. If the improved static balance witnessed as a result of yoga in this study, also translates to improved dynmamic balance, it will benefit athletes like rugby players, by improving their agility[33] and ability to maintain balance while performing movements during the rugby game.

Previous research has also indicated that balance training with eyes closed may also have a positive effect on the vestibular system[34]. Performing balance tasks without visual feedback increases the reliance on the somatosensory stimuli[35] which may have a training effect. Therefore, a combination of mind-body exercises including postures with eyes closed (as in some of the postures in the yoga group of this study) may have improved neural and sensory feedback systems thereby increasing sensitivity to somatosensory and vestibular feedback which may have improved balance and reduced postural sway in the yoga group.

Limitations

In the current study, only male players were contacted to participate in the study, therefore the application of these results is limited to males and further research is required to investigate the possible effects on females. The fact that all players were from the same club, means that the intervention practised and information provided to the yoga group, may have reached the control group also, and some control subjects may have practiced the intervention without our knowledge. Another limitation of the study was the fact that the assessor of the of the balance variables was not blinded to the intervention groups which may introduce some bias. However, since the results are mainly objective measures (e.g. force platform signals), the possibility of bias is reduced. The study could have been improved with a larger sample size, or a crossover design with sufficient time for washout of effects. Finally, while the sway significantly improved in the 2-legged eyes-closed test for the yoga group, the relevance of an eyes-closed balance test to balance control during a rugby game (with eyes open) is unknown. Hence, the results will remain exploratory until a more thorough longitudinal study is conducted on a larger sample with more applied balance tests for rugby players.

Conclusion

In conclusion, practicing yoga for 12 weeks significantly improved postural sway in the yoga group in the antero-posterior and medial-lateral directions in the two-legged eyes-closed balance task. If a reduction in postural sway is equivalent to improved balance, the yoga group improved balance compared to the control group (at least the antero-posterior and medial-lateral directions in two-legged eyes-closed task). Such balance improvements may assist rugby players by reducing unwanted movements on the rugby field, keeping joints and body parts aligned and possibly reducing injuries. Postural sway was also improved in most other balance tasks although the reductions in postural sway did not meet statistical significance. Therefore, the overall effect of yoga on 1-legged and 2-legged eyes open balance tasks remains speculative until further research can consistently show a positive

Take home messages

Yoga helps to reduce postural sway in the double-legged eyes-closed balance test in rugby players. Including yoga into the training routines of rugby players may therfore help to improve their balance, resulting in better stability and muscular control.

Conflicts of interest

The authors declare no conflict of interest.

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B.2 Study 2 Published in a peer-reviewed journal

Short Communication

Association between Hamstring Flexibility and Sprint Speed after 8 Weeks of Yoga in Male Rugby Players

Abstract

Background: A Yoga-asana-based intervention has demonstrated its ability to improve flexibility of individuals, but has not been explored in rugby players. We hypothesized that a structured yoga intervention may have an effect on flexibility and sprint performance in male rugby union players. **Methods:** It was a controlled trial research design and players were assigned using random sampling to one of the two groups; a yoga group (n = 16) that practised yoga for 1 h 2 times a week for 8 weeks in addition to their normal rugby training and a control group (n = 15) with regular rugby training but no yoga intervention. Yoga intervention included 32 yoga postures to address both the upper and lower extremities of the body. Data were collected during preseason and mid-season on hamstring flexibility (sit and reach test), and sprint performance (measured at 5, 10, and 30 m). **Results:** One hundred and twenty participants were screened and thirty-one players volunteered for the study. Interactions between groups and differences between pre- and post-intervention scores were analyzed using analysis of variance using SPSS (version 24.0). Significance was set at an alpha level of $P \leq 0.05$. The yoga group showed a small nonsignificant decrease (−1.2% ± 21.4%, P = 0.05) in hamstring flexibility compared to the control group which demonstrated a large significant decrease (−14.8% ± 23.7%) (mean % change ± 95% confidence interval [CI], P < 0.05). The yoga group also showed minor nonsignificant improvements in sprint times −3.2% ± 10.4%, −0.7% ± 9.0% for the 5 and 10 m sprints, respectively, (mean % change ± 95% CI) compared to controls −0.4% ± 10.2%, 0.4% ± 7.9%. **Conclusions:** Findings suggest that completing a structured yoga intervention alongside normal rugby training during the rugby season, yoga helped rugby players maintain their hamstring flexibility but did little to improve sprint performance during the season.

Keywords: *Acceleration, performance, range of motion, stretching*

Tilak Raj, Michael J Hamlin[1], Catherine A Elliot[1]

Department of Tourism, Sport & Society, Lincoln University, [1]Department of Tourism, Sport & Society, Faculty of Environment, Society and Design, Lincoln University, Lincoln, New Zealand

Introduction

Flexibility is a vital factor that has been associated with improved performance[1] and reduced sports-related injuries.[2] Many coaches, physicians, and trainers have accepted the important role flexibility plays in sports and have included exercises to increase and maintain flexibility in warm-up sessions before sports activity.[1] However, researchers have reported mixed results when examining the effects of flexibility on speed, athletic performance, and countermovement jump performance.[1,3-6] These mixed results have created confusion and debate among researchers, particularly around the association stretching has with subsequent explosive performance.[4,7-9] To date, only a few researchers have explored the chronic effect of a stretching routine or flexibility intervention on rugby players.[10]

Yoga is a combination of physical postures (Asana), breathing exercises (Pranayama), and meditation (Dhyana), which focuses on the physical and mental aspects of an individuals' movements.[11] Improved flexibility is one of the major benefits of yoga practice and yoga has been shown to have similar effects compared to stretching exercises.[12] This study employed Hatha-yoga, which uses various body positions to stretch muscles in conjunction with an emphasis on controlled breathing exercises.

The aim of the study was, therefore, to assess whether a yoga (stretching) intervention practised by male rugby players alongside their usual rugby training had any effect on their subsequent flexibility and sprint performance.

Address for correspondence:
Mr. Tilak Raj,
P.O. Box: 85084, Lincoln 7647, Canterbury, New Zealand.
E-mail: tilakraj.tilakraj@lincolnuni.ac.nz

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Methods

Participants

Initially, 120 players were screened, and 31 male rugby players (19.5 ± 0.9 years) [Table 1] from a local rugby union football club volunteered for the study [Figure 1]. However, only nineteen players (yoga n = 12) (control n = 7) completed the study due to injuries and personal circumstances. All players were novices to the practice of yoga. Players were randomly assigned either to the yoga group (practised yoga for 1 h, two times/week for 8 weeks in addition to their normal rugby training) or the control group (continued with their normal rugby training without yoga). All players were free from any current or previous injuries. All players were also informed about the possible risks of volunteering for this study and provided written informed consent before the study. Following the Declaration of Helsinki, this research was approved by the Institutional Human Ethics Committee.

Table 1: Physical characteristics and playing experience of the yoga and control groups

Group	Yoga group	Control group
Age (years)	19.1±0.9	19.6±0.9
Height (cm)	181.3±8.1	182.7±4.1
Weight (kg)	88.9±18.7	85.5±9.4
BMI (/m²)	26.6±5	26.6±3.3
Rugby experience (years)	4.0±1.3	3.5±1.3

Data are mean±SD. SD: Standard deviation

Design of the study

A yoga intervention was exclusively designed for rugby players and delivered by a yoga instructor (registered exercise professional, New Zealand). Players were required to complete 3, 30 m sprints to measure the physical performance. All participants were in the same yoga class, and all sessions were completed in a large open fitness room.

Assessment

Flexibility of the hamstrings

A baseline examination was carried out 1–2 weeks before the yoga intervention and again 1–2 weeks after the last yoga session. The hamstring flexibility of players was measured in a seated position in front of a Flex-Tester© box (Novel Products, Inc.; Rockton, IL, USA). The hamstring flexibility test consisted of 3 sit-and-reach tests. Players were not allowed to flex their knees during the test and players were required to have a 2 min rest between each attempt with the best attempt used in the analysis.

Sprint performance

After completing the hamstring flexibility test, sprint performance was measured using three 30-m sprints. The

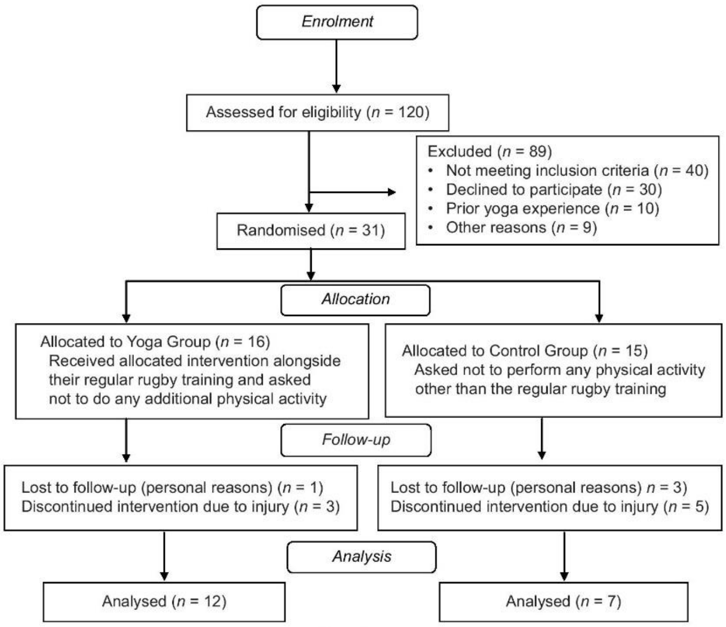

Figure 1: Flowchart describing the selection and categorisation of subjects from the rugby clubs for the present analysis

sprint was analyzed in two acceleration phases (5 and 10 m) and maximal velocity (30 m).[13] Each participant completed the sprint from a standing start position. Sprint time (to the nearest 0.01 s) was recorded using a set of electronic speed-timing lights placed at 5, 10, and 30 m (SmartSpeed, Fusion Sport Ltd., Australia). A 2 min recovery was required between each sprint, and the best of 3 attempts was used in the analysis. All players were asked not to perform any strenuous exercise in the 24 h before testing. The testing was completed at the same time of day on a large covered slip-free floor area under similar climatic conditions.

Intervention

Yoga classes were offered two times a week for 8 weeks, which started at the beginning of the rugby season. The average attendance rate for the yoga group was 75% (12 sessions), with some players attending all (16) sessions, whereas others only attended (9) sessions. Each yoga session consisted of a warm-up of 10 min with Surya-namaskar (dynamic stretching sequence of postures) followed by 35 min of yoga postures (10 min standing, 10 min sitting, and 15 min of supine and prone postures and a mix of static and dynamic postures) and 10 min relaxation in the final resting position (lying in the supine position without any stretching exercise). A total of 5 min was allocated for the transition between the yoga postures.

Data extraction

The mean of the fastest sprint time and highest flexibility scores of individual players at pre- and post-testing were recorded on Excel and later were used in the group analyses.

Data analysis

The number of participants required for the study was calculated using a spreadsheet with the smallest worthwhile change in performance being 1.0% and the typical error or within-subject standard deviation (SD) in similar tests of 0.7%. This calculation estimated we needed 7 participants in each group in a controlled trial research design. Interactions between group and differences between pre- and post-intervention scores were analyzed using analysis of variance. Statistical analyses were performed using SPSS 24 for Windows (SPSS, Inc., Chicago, IL, USA). Significance was set at an alpha level of $P \leq 0.05$. Data given represents the mean ± SD unless stated otherwise.

Results

The yoga group showed a small decrease (−1.2% ± 21.4%) in hamstring flexibility compared to the control group which demonstrated a significant decrease (−14.8% ± 23.7%) (mean % change ± 95% confidence interval [CI], $P < 0.05$). In addition, the yoga group showed a small, but nonsignificant improvement of 3.2% ± 10.4, and −0.7% ± 9.0%, in their sprint time when compared to the control group –0.4% ± 10.2%, 0.0% ± 7.9%, in 5 and 10 m, respectively [Table 2].

Discussion

This study found that rugby players that undertook 8 weeks of static and dynamic stretching during a weekly 1-h yoga intervention, in addition to their normal rugby training sessions, either maintained or had a minimal decrease in their hamstring flexibility compared to players who did the rugby training only. However, this flexibility training through the yoga intervention did little to improve short sprint performance between the groups (e.g., 5, 10, and 30-m sprint time), we found no significant beneficial improvement in sprint performance in the experimental group (receiving yoga intervention) compared to controls.

The controversial issue of stretching to improve performance is based on several postulated mechanisms. Dynamic movement requires the contraction and elongation of the muscle-tendon unit (and thereby, movement of the limb around the joint). This shortening and stretching (stretch-shortening cycle), relies on the elastic proprieties of the tendon to enable the release of potential energy. Hence, the elastic property of the muscle-tendon unit is crucial and is influenced by the stiffness of both tissues. It is believed that greater compliance (i.e., less stiffness) in these tissues improves energy storage, thereby enhancing muscle performance.[14] Given that the stretching (yoga) group improved flexibility, compared to the control group, which may have increased muscle compliance, this did not seem to change muscle performance during sprinting in the rugby players measured in this study. This suggests that either tissue compliance did not change (and the relative

Table 2: Hamstring flexibility and 5, 10, 30 m sprint time of the yoga and control group

	Control group			Yoga group			Between group pre post (%) change (±95% CI)
	Pre (*n*=7)	Post (*n*=7)	Control group pre post (%) change (±95% CI)	Pre (*n*=12)	Post (*n*=12)	Yoga group pre post (%) change (±95% CI)	
Flexibility (cm)	32.3±9.4	26.0±12.9	−14.8 (23.7)	31.1±11.1	30.9±9.4	−1.2 (21.4)	17.3 (30.8)*
5 m Sprint (s)	1.01±0.07	1.01±0.15	−0.42 (10.21)	1.07±0.05	1.04±0.14	−3.2 (10.4)	−2.7 (10.4)
10 m Sprint (s)	1.78±0.11	1.80±0.23	0.37 (7.85)	1.82±0.14	1.81±0.20	−0.7 (9.0)	−1.1 (8.4)
30 m Sprint (s)	4.35±0.27	4.57±0.60	4.37 (7.13)	4.52±0.31	4.54±0.40	0.2 (5.4)	−4.1 (6.7)

Data are raw mean±SD of each group with the difference within and between groups given as the percent mean difference±95% CI. *Statically significantly (P<0.05). SD: Standard deviation, CI; Confidence interval increase in flexibility is due to other mechanisms), or that there is little effect of increased compliance on sprint performance. On the other hand, while the yoga group showed an increase in flexibility compared to the control group (an average of 17.3%), in reality, the significant change between groups is probably because the flexibility in the control group decreased (−14.8%) while the flexibility in the yoga group changed little (−1.2%). Therefore, if the flexibility did not change in the yoga group, we would not expect to find greater muscular compliance and thus little change in performance.

Previous research has found that yoga practiced for 75 min two times/week for 20 weeks (average of 150 min/week) improved sit and reach scores by approximately 13 cm in the first 10 weeks and 17 cm at the end of training in healthy adults.[15] The players in the current study completed approximately 90 min/week for 8 weeks which may indicate a larger stretching dose is required to achieve significant flexibility changes. In addition, not all players in the current study made every yoga session with an attendance rate of only 60% compared to 78% in the Petric's[15] study. Overall, this would suggest the players in the current study received substantially less muscle stretching time which resulted in a lower stretching dose and therefore less muscle adaptation. We would recommend that any future studies in this area should allow players to complete at least 150 min of yoga per week. Whether the 150 min per week of muscle stretching (for a minimum of 12 and up to 20 weeks) can successfully be incorporated into shorter sessions (e.g. 30 min on 5 days/week) requires further investigation.

It is also possible, that due to muscle damage suffered either at training or during a match, which can result in substantial swelling and edema,[16] the effectiveness of any chronic stretching intervention, was reduced. We speculate that perhaps the stretching employed in the current study by the yoga group was enough to buffer any losses in sprint performance associated with such muscle damage since the yoga group sprint times did not decrease as much as the control group sprint times. However, this is speculative and would require further research before this theory can be confirmed.

Conclusions

Yoga practiced for 1 h twice a week over an 8-week period was sufficient enough to maintain hamstring flexibility in male rugby players compared to players that did not complete yoga; however, the maintenance of flexibility did not result in any significant improvement in sprint performance in these players. We would recommend that any stretching intervention (including yoga) should be practiced for at least 150 min/week over a longer period (i.e., 20 weeks) to allow adaptations to occur which may result in muscular performance change.

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Conflicts of interest

There are no conflicts of interest.

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